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Effect of different size cerium oxide nanoparticles on performance and emission characteristics of variable compression ratio engine fuelled with diesel-palm biodiesel blends

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Abstract— *An experimental investigation was carried out to evaluate performance and emission characteristics of direct injection, single cylinder, water cooled variable compression ratio diesel engine using cerium oxide nanoadditive of two different particle size dispersed in diesel and palm Biodiesel blends B10 and B20. In first part of experiment CERIA21(cerium oxide of particle diameter in the range of 21-30nm) and CERIA41(cerium oxide of particle diameter in the range of 41-50nm) are blended with diesel and palm biodiesel blends B10 and B20 in dosage of 150 ppm using ultrasonic bath stabilizer at 15 min sonication time. The stability characteristic of prepared fuel blends with CeO2 was find out, The results of which revealed that CERIA21 blended fuel has high stability and less percentage transmittance compared to CERIA41 blended fuels, this is due to better suspension of fuel and less agglomeration for smaller particles. Whole experiment was carried out using following fuels: neat diesel, B10, B20, B10+CERIA21, B10+CERIA41, B20+CERIA21, B20+CERIA41. The experimental results showed that as biodiesel concentration increased BSFC and brake thermal efficiency decreases. Addition of CeO2 in base fuel improves BTE and reduce BSFC owing to its high surface area to volume ratio, thermal conductivity and oxidation stability. At full load BTE was improved by 3.62%, 2.95%, 3.20% and 2.43% with B10+CERIA21, B10+CERIA41, B20+CERIA21, B20+CERIA41 respectively at higher CR. Highest BTE and lowest BSFC was observed with B10+CERIA21 at 24.68% and 0.3204 kg/kw.hr at full load and CR16.5. At lower CR fuel injected in colder combustion chamber which provides insufficient heat for compression which ultimately increase BSFC and reduce BTE. Carbon monoxide(CO) and hydrocarbon(HC) emission were reduce with B10 and B20 due to higher oxygen content than diesel, addition of CeO2 further reduces these pollutants. with B10+CERIA21, B10+CERIA41, B20+CERIA21 and B20+CERIA41 CO emission reduced by 38.88%, 22.22%, 56.25% and 37.5% at CR 16.5 whereas HC reduced by 11.76%, 8.25%, 12.65% and 8.86% respectively. NOx increases with B10 and B20 compared to diesel due to high cylinder temperature, CeO2 addition further increases NOx emissions. Highest NOx observed with B20+CERIA41 as 744 ppm. Overall performance with CERIA21 was better than CERIA41.*

Keywords— cerium oxide nanoparticles, Palm biodiesel-diesel blends, NOx reduction, variable compression ratio, CI engine

I. INTRODUCTION

Diesel engines are receiving more and more attention in transportation, industrial and agricultural and automobile sectors because of its reliability and high efficiency due to higher compression ratio and ability to operate at lean fuel-air mixture. On the contrary diesel engines are emerging as one of the major air pollution sources, gases exhausted from diesel engines are responsible for climate changes and greenhouse effect which affects plants, animals and human alike. In addition, new petroleum reserves appear to grow arithmetically while the consumption growing geometrically. Under this situation, when consumption overtakes discovery, the world will be leading to an industrial disaster. Due to the rapid depletion of petroleum products and the strict rules imparted by the government to engine manufacturers and consumers to follow the emission norms to save the environment from diesel engine pollution have obliged many researchers to identify alternative techniques for diesel engine which can improve performance and emission control. Most of the researchers have contributed their efforts to reduce the emissions from the diesel engines in three ways 1) engine design modification 2) fuel adulteration 3) treatment of the exhaust gas.

Fuel adulteration is widely accepted by many researchers and biodiesel emerged as a major alternative for diesel. Biodiesel produced from various oils such as palm, jatropha, karanja, cotton seed, neem etc. by transesterification process. Biodiesel fuel has healthier properties than those of diesel fuel such as renewable, non-biodegradable, eco-friendly, nontoxic, and free of sulphur. The combustion of fossil fuels is linked with emissions such as HC, CO, NOx, SOx, which are currently the major global sources of pollution. Palm biodiesel has higher cetane number than diesel and almost same energy content due to which it can be directly used as replacement of diesel. Overall performance and efficiency of engine reduced with biodiesel because of its low energy content and high viscosity.

Nanoparticles acts as a combustion catalyst which improves engine performance by enhancing physiochemical properties and combustion characteristics when added in base fuel. Wide variety of nanoparticles available which can be used as fuel additives such as Aluminium, Boron, Zinc, Cerium oxide, Aluminium oxide, magnetic nanofluid and carbon nanotubes. Number of experiments has been done using these additives in diesel and results of which indicates that nanoparticles added fuel show higher efficiency and lower BSFC, in addition HC, CO and soot emissions reduces with nanoparticles blended fuel because addition of nanoparticles in base fuel reduces ignition delay and rise in temperature inside combustion chamber which burn of carbon deposits inside the chamber and promotes complete combustion.

Biodiesel used for present work is palm biodiesel and nanoparticles used are Cerium oxide of particle size 21-30nm and 41-50nm. Experiment is conducted using compression ratio of 16.5 and 13.89

II. FUEL PREPARATION

2.1 BIODIESEL PRODUCTION

The Palm oil was collected from local market. For preparation of palm biodiesel from palm oil transesterification process was used. The palm oil was preheated into flask with temperature (between 60-80°C) until the palm oil contents were in a semi-transparent, dark brown, viscosed liquid form, after that preheated palm oil was mixed homogonously and stored in container. The alkali catalyst NaOH and methanol solution was prepared to produce sodium methoxide and stir this mixture for 10 minute for proper mixing. After that the mixture of Naoh and methanol is added into preheated palm oil and stir this mixture vigorously for 40 to 50 minutes to start the transesterification reaction. After the specific duration of the reaction completed, the reaction's product was allowed to settle over night (24 h). The reaction's result was two distinct liquid phases; the first was the Palm Oil Methyl Ester (POME) or the biodiesel on the top and the second was the denser phase of glycerol. Methyl ester was separated by separating funnel. Then mixture of Palm Biodiesel is washed by hot water three times. Glycerol is highly soluble in water and biodiesel is not soluble in water which make a different layer of water mixing glycerol which is separated by funnel and biodiesel is obtained.

TABLE 1 PROPERTIES OF PALM BIODIESEL

Parameters	Units	Value
Density @ 15 C	KG/M3	895
Kinematic viscosity@40 C	CP	15.24
Kinematic viscosity@110 C	CP	10.25
Iodine value	-----	118
Acid value	MGKOH/GM	28
Flash point	C	134
Fire point	C	163
Gross calorific value	KJ/KG	42665
Cetane number		66

2.2 PREPARATION OF FUEL BLENDS

At first palm biodiesel blended with pure diesel and prepared blends B10 (90% diesel+ 10% palm biodiesel) and B20(80% diesel+ 20%palm biodiesel), CeO2 nanoparticles CERIA21 and CERIA41 was purchased from nano research lab Pvt. Ltd, Jamshedpur. For preparing blends with nanoparticles first 1 lit sample of each B10 and B20 taken, than CERIA21 is added in the proportion of 150 ppm in B10 and B20 for making B10+CERIA21 and B20+CERIA21, same method is adopted for making B10+CERIA41 and B20+CERIA41. After adding of cerium oxide in the fuel it is shaken well and then it is placed on ultrasonic bath stabilizer (50 W, 33 kHz) for making stable and uniform suspension of CeO2 in the fuel. The ultrasonic bath stabilizer was provided by chemical department of Krantiguru Shyamajikrishna Verma kachchh University, India. Fig.1 shows blending of CeO2 in ultrasonicator.

Fig.1 blending of CeO2 on ultrasonicator

fig.2 cerium oxide nanoparticles

Table 2 Details of cerium oxide nanoparticles

Item	Specifications
Appearance	Yellow powder
Average particle diameter	21-30 nm
	41-50 nm
Purity	99.9%
Melting point	2600°C
Relative density	7.13

2.3 STABILITY ANALYSIS OF FUEL

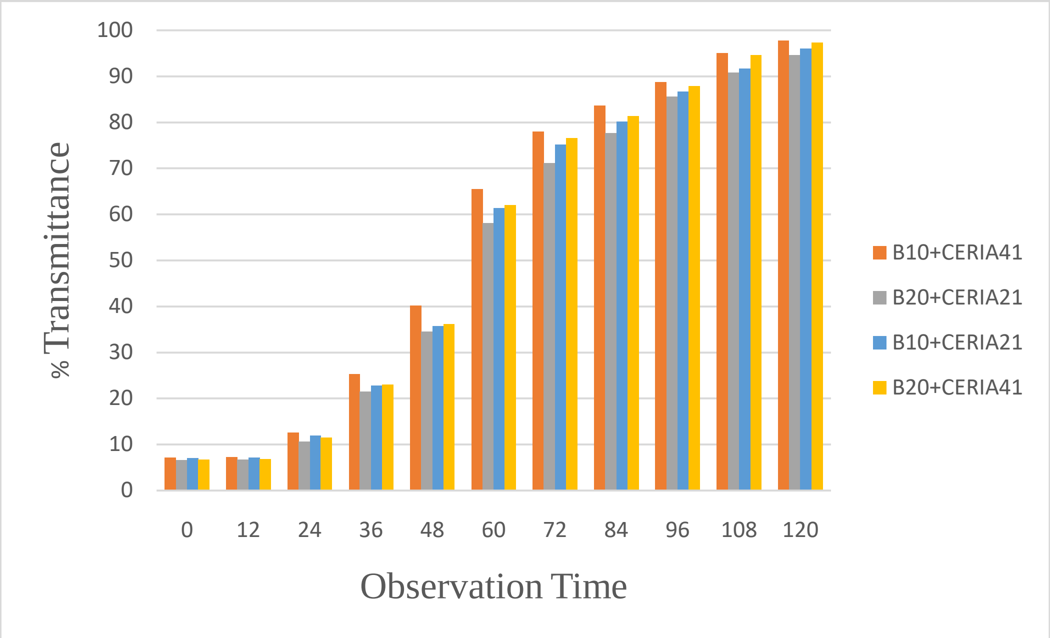

Fig.3 stability of CeO2 blended fuels for 15 min sonication time

Stability of cerium oxide added nano fuels B10+CERIA41, B20+CERIA21, B10+CERIA21 and B20+CERIA41 for 15 minutes sonication time was checked using digital balanced cell calorimeter and from the results available %Transmittance calculated and plotted in graph against observation time. It is clearly evident from the graph that upto 36 hours of sonication %transmittance rising slowly and it is around 20% which means all fuels are stable upto 36 hours. After that %transmittance soared sharply which indicates nanoparticles started separating from base fuel. After 120 hours of sonication %transmittance for all fuels for B10+CERIA21, B10+CERIA41, B20+CERIA21 and B20+CERIA41 were 95.94%, 97.72%, 94.62% and 97.27% which means CERIA particles completely separated from base fuel. CERIA21 are more stable than CERIA41, after 120hours %transmittance for CERIA21 is 3.10% less than CERIA41.

III. Experimental setup

Experimental investigations were carried out on a on a single cylinder, four-stroke water cooled, naturally aspirated, direct injection variable compression ratio diesel engine. Engine has maximum compression ratio of 16.5 and engine speed of 1500 rpm. Engine generates brake power of 5.2 KW. For measurement of fuel consumption burette is connected with fuel tank with three way valve. Engine is coupled to eddy current dynamometer to measure torque. Load cell is connected to dynamometer to vary load. K-type thermocouple used to measure inlet and exhaust temperature of gas, cooling water and calorimeter. While RTD used to measure ambient temperature. Engine specifications are given in table 2.

FIG.4 Engine setup

1. Single cylinder four stroke diesel engine
2. Eddy current dynamometer
3. Rotameter
4. Air box
5. Fuel tank
6. Burette
7. Fuel control valve
8. Load cell
9. Pressure sensor
10. Performance testing machine
11. AVL exhaust gas analyser
12. Exhaust probe

TABLE 2
ENGINE SPECIFICATION

Parameter	Specifications
Make	Brand new kirloskar
Model	AV1
Method of cooling	Water cooled
Rated power	5 HP
Engine speed	1500 RPM
Bore × Stroke	87 mm × 110 mm
Volume	553 c.c
Compression Ratio	Variable from 16.5 to 8.73

IV. EXPERIMENTAL APPROACH

In order to find out effect of cerium oxide nanoparticles of 21-30nm diameter and 41-50nm diameter on variable compression ratio diesel engine this experiment has been done using seven fuels: neat diesel, B10, B20, B10+CERIA21, B10+CERIA41, B20+CERIA21 and B20+CERIA41. Observations was made using two compression ratios 16.5 and 13.89. Cerium oxide added in proportion of 150ppm in all fuels. In performance measurement brake power, brake specific fuel consumption and brake thermal efficiency was calculated using experimental data for each fuel. In exhaust emissions using AVL exhaust gas analyzer proportion of exhaust constituents such as carbon monoxide, hydrocarbon, oxides of nitrogen and carbon monoxide observed and noted for each fuels. After completion of experiment observed data was compared with and without nanoparticles at both CR improvement in engine performance find out. Performance and emission characteristics at CERIA21 and CERIA41 was also compared in order to find out effect of particle size on emission and performance.

V. RESULT AND DISCUSSION

5.2 ENGINE PERFORMANCE DATA

Engine performance parameter like brake specific fuel consumption and brake thermal efficiency respectively are discussed with diesel fuel, B10 and B20 with CERIA21 and CERIA41 at different load conditions.

5.2.3 Brake Specific Fuel Consumption

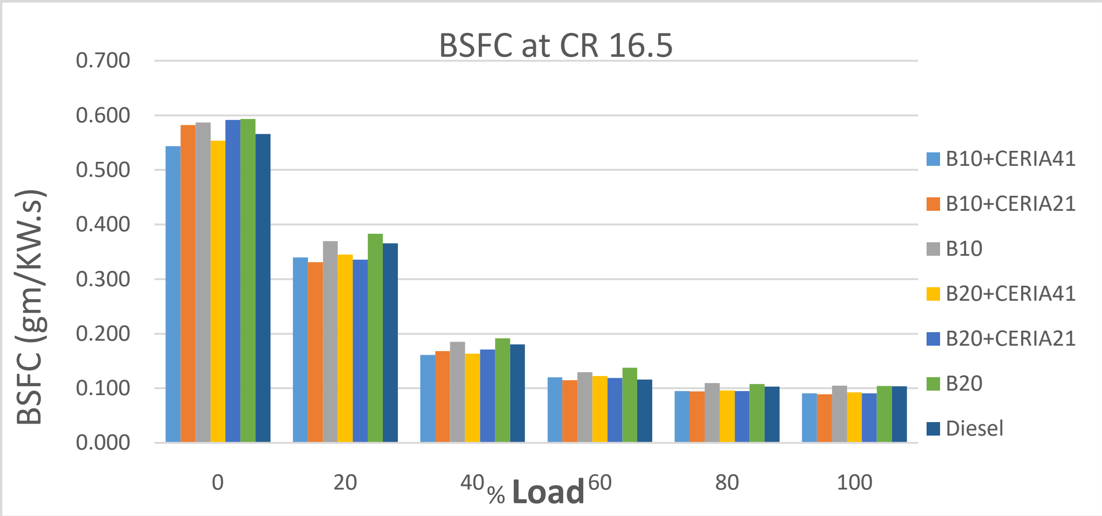

Fig. 5 BSFC Vs. % Load at CR 16.5

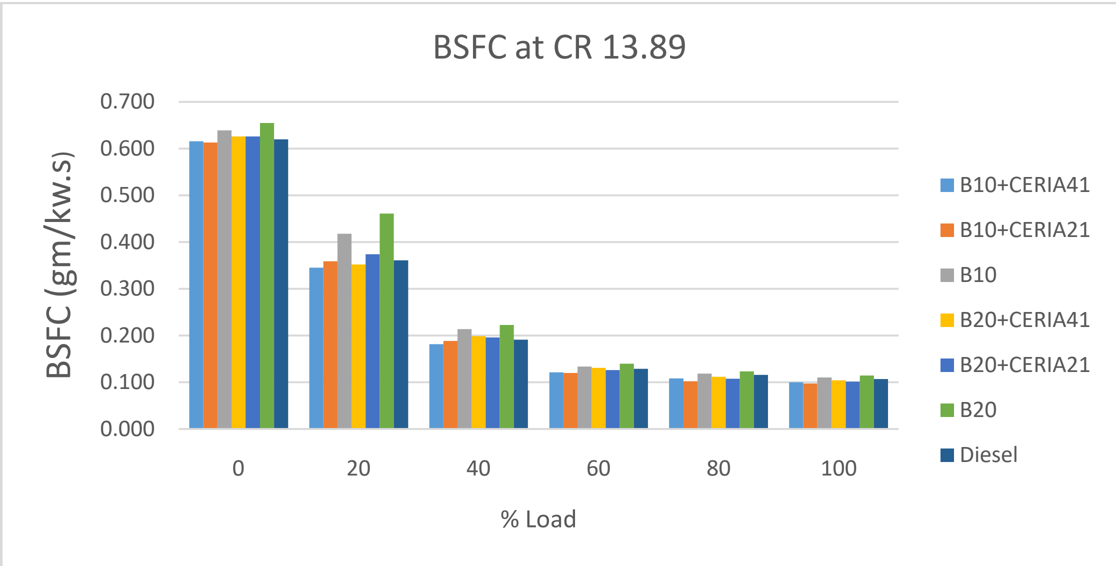

Fig. 6 BSFC Vs. % Load at CR 13.89

Brake specific fuel consumption (BSFC) is a measurement of fuel consumption per unit brake power. That means increasing brake power decrease BSFC, so BSFC decreases with increase in engine load. BSFC is higher for B10 and B20 as compared to neat diesel because of lower energy content of palm biodiesel than diesel. As shown in fig.5 at full load and 16.5 CR BSFC for diesel, B10 and B20 was 0.3708, 0.3816 and 0.3888 kg/kw.hr respectively. At higher load BSFC slightly increased for diesel because of rich mixture and lack of oxygen, whereas for biodiesel BSFC decreased at higher load because of higher oxygen content. Addition of CeO2 reduce BSFC further as it promote the combustion phenomena by reducing ignition delay. At full load and CR of 16.5 BSFC for B20+CERIA21, B20+CERIA41, B10+CERIA21 and B10+CERIA41 were 0.3276, 0.3348, 0.3204 and 0.3276 kg/kw.hr respectively. At lower compression ratio BSFC was increased the possible reason for this trend could be that with at lower CR, the maximum cylinder pressure decreases due to the fuel injected in cooler combustion chamber and this leads to low effective power. Therefore, fuel consumption per output power will increases which can be seen in fig.6. At CR of 13.89 BSFC for B20, B20+CERIA21, B20+CERIA41, B10, B10+CERIA21 and B10+CERIA41 were 0.3852, 0.414, 0.3636, 0.3744, 0.396, 0.3492 and 0.360 kg/kw.hr respectively, so all in all BSFC with higher CR and with nanoadditives are lower. Least BSFC was given by B10+CERIA21 at 0.3204 kg/kw.hr.

5.2.3 Brake Thermal Efficiency

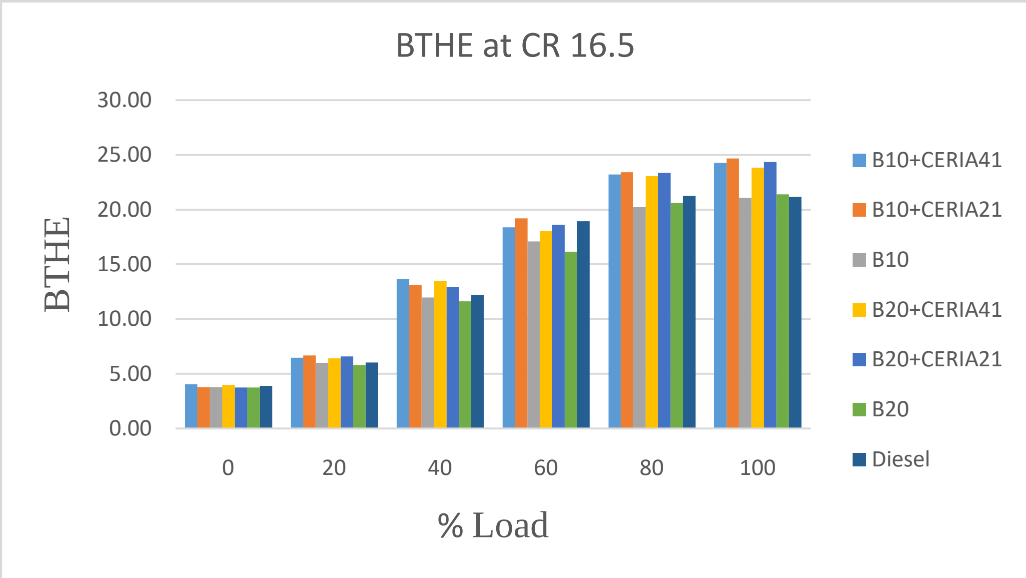

Fig. 7 BTE Vs. % Load at CR 16.5

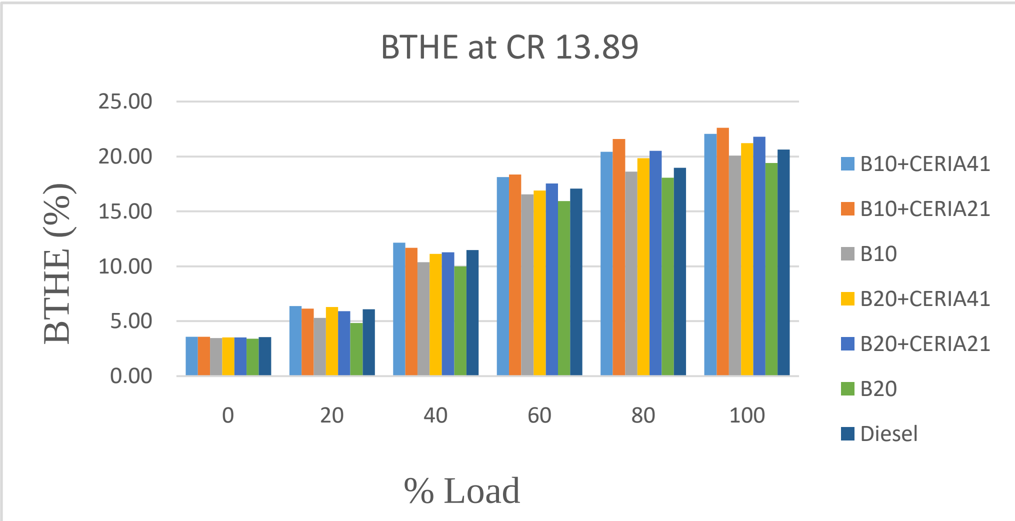

Fig. 8 BTE Vs. % Load at CR 13.89

The variation in brake thermal efficiency for the fuel considered in the test is shown in Fig7 and fig.8. The brake thermal efficiency increases with increase in engine load for all fuels. As shown in Fig the brake thermal efficiency using blend of diesel palm biodiesel blends B20 and B10 is significantly lower compared to diesel. This could be due to lower calorific value of biodiesel. At higher load because of rich mixture and lack of oxygen in fuel thermal efficiency of pure diesel was decreased at full load. By adding CeO2 nanoparticles of particle diameter 21-30 nm and 41-50 nm in B10 and B20 efficiency was increased, this is due to microexplosion of fuel droplet which improves air fuel mixing and accelerate combustion results in increase the brake thermal efficiency using nanoparticle blended fuel, moreover CeO2 increases calorific value of base fuel. As shown in fig.7 with addition of CERIA21 brake thermal efficiency of B10 and B20 was increased by 3.62% and 2.95% respectively, Whereas CERIA41 added B10 and B20 show rise in efficiency of 3.20% and 2.43% respectively at CR of 16.5 and at full load operation. It was observed from experimental data that compression ratio plays significant role in diesel engine, at CR of 13.89 BTE of engine decreased this can be attributed as at lower CR heat required for combustion is not available which in turns reduces the efficiency of engine. At CR of 13.89 BTE was reduced by 0.54%, 1.98%, 2.54%, 2.02%, 0.97%, 2.07% and 2.21% for diesel, B20, B20+CERIA21, B20+CERIA41, B10, B10+CERIA21 and B10+CERIA41 respectively at full load. Highest BTE was observed with B10+CERIA21 at 24.68%. CERIA21 gives slightly higher efficiency than CERIA41 because of smaller particle size better suspension in base fuel created which gives optimum performance.

5.3 ENGINE EMISSION CHARACTERISTICS

Variation of emission parameter like unburnt hydro carbon (HC), carbon monoxide (CO) and nitrogen oxide (NO) at two different compression ratio 16.5 and 13.89 with different load conditions are recorded and discussed as below.

5.3.1 Hydro Carbon (HC)

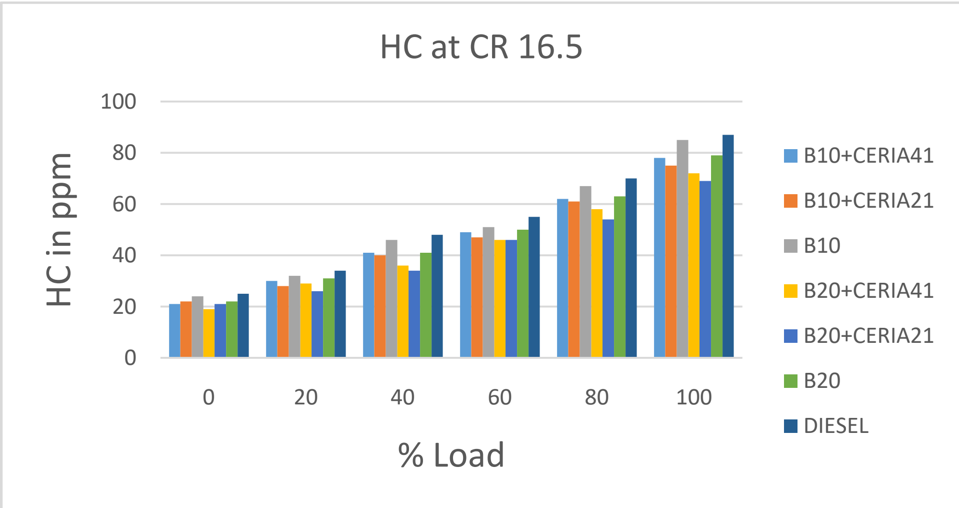

Fig. 9 HC emission Vs. % Load at CR 16.5

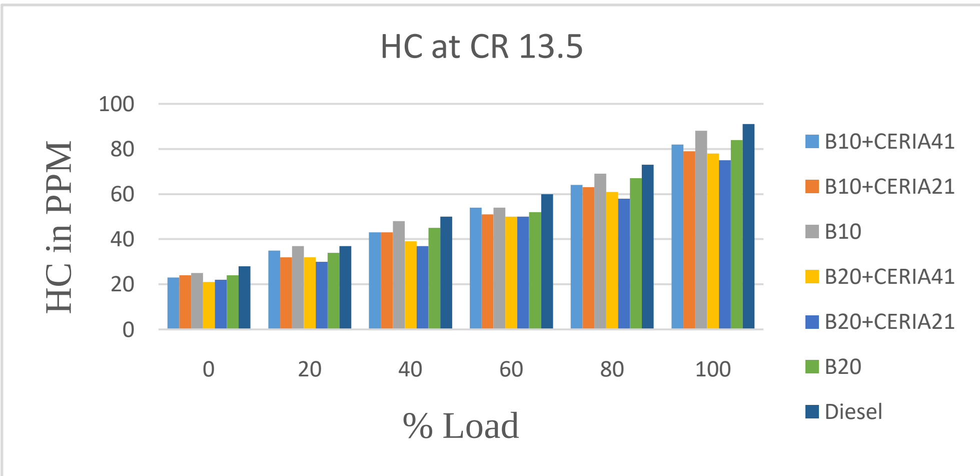

Fig. 10 HC emission Vs. % Load at CR 13.89

The variation of hydrocarbon (HC) emission is represented in Fig.9 and fig.10. The hydrocarbon emission from the engine is direct indication of incomplete combustion of fuel. As seen in the Figures, the increase in biodiesel ratio in the fuel blends reduced HC emissions. Diesel has higher HC emission than its biodiesel blends at all loads this is due to more carbon content and lower oxygen content in diesel. At full load HC emission for diesel, B10 and B20 were 87, 85 and 79 ppm respectively at CR16.5 and 91, 84 and 88 ppm respectively at CR13.89. At lower CR less heat of compression available which increases ignition delay and hence also generate more HC. CeO2 is oxygen donating catalyst which reduces ignition delay and HC emission. For B10+CERIA21, B10+CERIA41, B20+CERIA21 and B20+CERIA41 HC emission was 75, 78, 69 and 72 ppm respectively at CR16.5 and 79, 82, 75, 78 ppm respectively at CR13.89. Least HC was observed with B20+CERIA as 69 ppm which was 20.12% less than diesel. Moreover CeO2 of 21-30nm particle size has 3.7% to 4% lower HC emission than 41-50 nm sized particles.

5.3.2 Carbon Monoxide (CO)

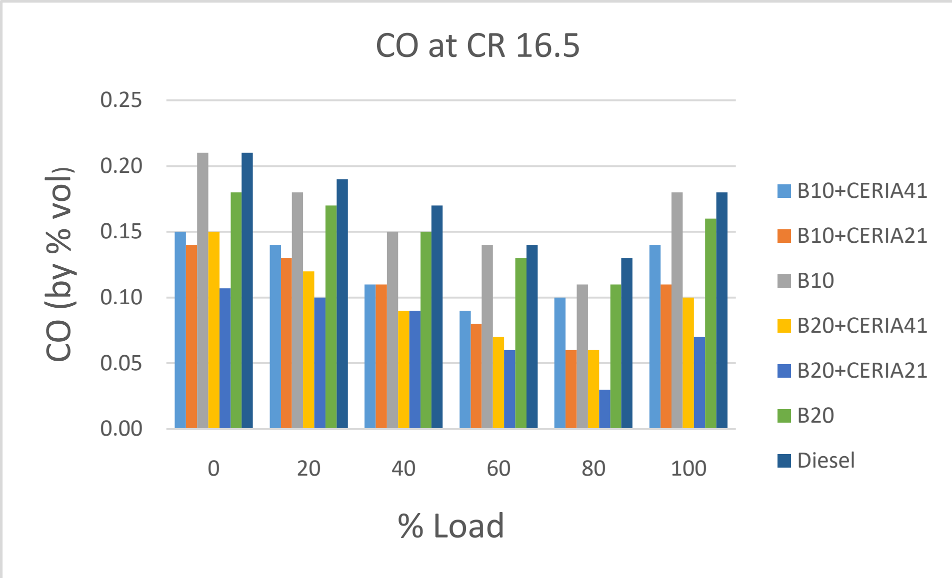

Fig. 11 CO emission Vs. % Load at CR 16.5

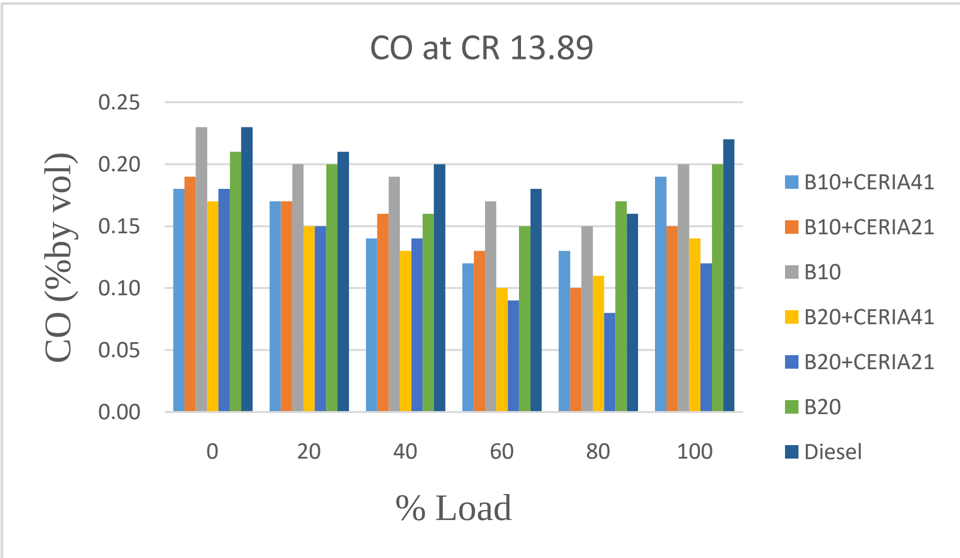

Fig. 12 CO emission Vs. % Load at CR 13.89

Fig.11 and fig.12 represents variation in CO emission with increase in engine load. CO is produce due to improper air fuel mixture, lack of oxygen in fuel which cause incomplete combustion and lack of temperature inside combustion chamber. As load increases due to increase in temperature CO emission decreases. Diesel has higher CO emission compared to B10 and B20 due to lower oxygen content. At full load CO emission for diesel, B10 and B20 were 0.19%,

0.18% and 0.16% respectively at CR 16.5 and 0.22%, 0.20% and 0.20% respectively at CR of 13.89. Decreasing CR increase CO content because at lower CR, insufficient heat of compression delays ignition and so CO emissions increase. For diesel, B10 and B20 CO increased by 15.7%, 11.11% and 12.5% respectively at CR of 13.89. cerium oxide addition in base fuel reduces CO further as cerium oxide acts as an oxygen donating catalyst which reduces ignition delay and enhanced flame temperature which promote complete combustion and reduce CO. with B10+CERIA21, B10+CERIA41, B20+CERIA21 and B20+CERIA41 CO emission reduced by 38.88%, 22.22%, 56.25% and 37.5% at CR 16.5 and 25%, 10%, 40% and 30% respectively at CR 13.89 as compared to base fuel. Lowest CO was observed with B20+CERIA at CR16.5 of 0.07% by volume. CERIA21 has lower CO than CERIA41 because of proper suspension of particles in base fuel and higher stability.

5.3.3 Nitrogen Oxides (NOx)

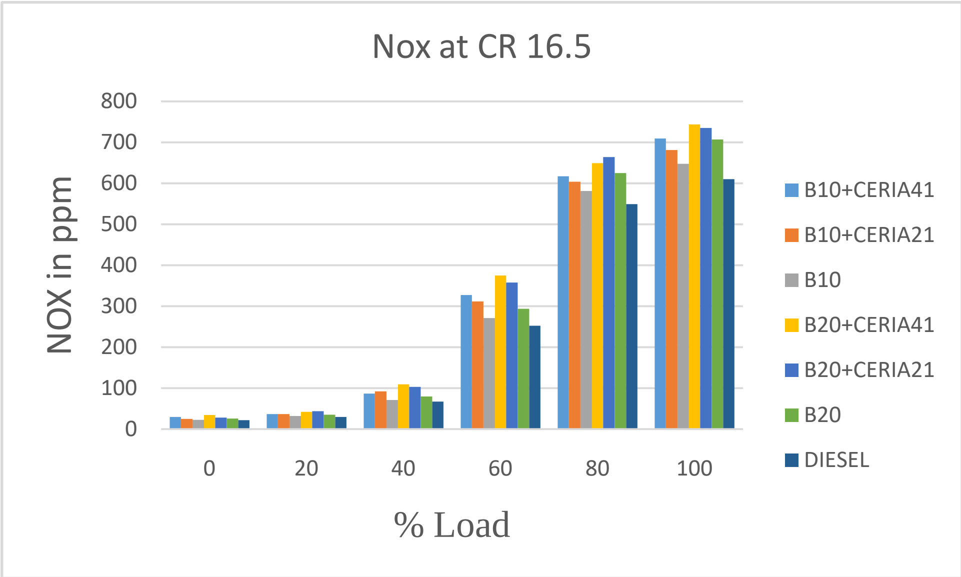

Fig. 13 NOx emission Vs. % Load at CR 16.5

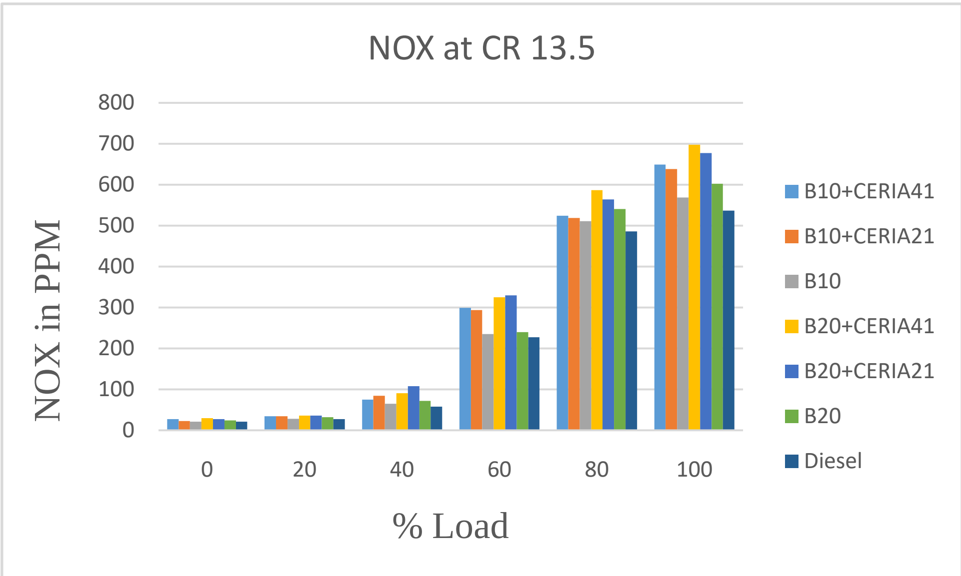

Fig. 14 NOx emission Vs. % Load at CR 13.89

Apart from CO and HC emission, the third main pollutant is oxides of nitrogen. Fig.13 and fig.14 shows variation in NOx emission tested fuels. It can be observed that the emission of NOx was increases with increase in engine loads for both the fuels. NOx emissions depends on temperature inside combustion chamber and exhaust gas temperature. NOx emission for biodiesel blends were less than diesel because of higher oxygen content which increased cylinder gas temperature. NOx for diesel, B10 and B20 at full load were observed with 610, 648 and 707 ppm respectively at CR16.5 and 537, 569 and 602 respectively. Reducing CR decreased NOx as at lower CR13.5 ignition delay increases which reduced flame temperature. The addition of cerium oxide increases NOx further because of rise in temperature. NOx for B10+CERIA21, B10+CERIA41, B20+CERIA21 and B20+CERIA41 observed at 681, 709, 735 and 744 ppm respectively at CR16.5 and 638, 649, 677, 698 ppm respectively at CR13.89. Highest NOx observed with B20+CERIA41 at 744 ppm.

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VI. CONCLUSION

The performance and emission characteristics of single cylinder variable compression ratio diesel engine using diesel, palm biodiesel and its blends with cerium oxide nanoparticles with average particle diameter of 21-30 nm and 41-50 nm are investigated. Based on experimental results following conclusions are derived:

1. Stability study revealed that with reducing nanoparticle size better suspension fuel is created. CERIA21 blended fuel stay stable longer than CERIA41 blended fuel. Stability of cerium oxide blended B10 and B20 was found to be 48 hours.

2. Brake thermal efficiency increases with engine load for all fuels. B10 and B20 show less BTE than diesel due to lower heating value of palm biodiesel. Cerium oxide nanoparticles acts as combustion catalyst which promotes complete combustion and improve performance when added in base fuel. BTE increases by adding CERIA21 and CERIA41 in B10 and B20. At CR16.5 with CERIA21 added fuel BTE was increased by 3.62% and 2.95% respectively, Whereas CERIA41 added B10 and B20 show rise in efficiency of 3.20% and 2.43% as compared to base fuel without nanoparticles. At lower CR BTE reduced because of less heat available for combustion. CERIA21 shows slightly higher BTE than CERIA41. Highest BTE was observed with B10+CERIA21 at 24.68%.

3. BSFC is higher for B10 and B20 as compared to diesel because of lower energy content of palm biodiesel. BSFC decreased with increase in engine load. CERIA21 and CERIA41 blended B10 and B20 decreased BSFC as cerium oxide reduce ignition delay period and promote better atomization of fuel. Lowest BSFC observed with B10+CERIA21 at 0.3204 kg/kw.hr at CR16.5. At all conditions BSFC for CERIA21 was slightly lower than CERIA41 because of smaller particle size surface area to volume ratio is high. At lower CR BSFC increased because of lower heat content inside cylinder. At CR13.89 BSFC was increased by 8.98%, 9.89%, 10.98% and 11.89% for B10+CERIA21, B10+CERIA41, B20+CERIA21 and B20+CERIA41 respectively.

4. CO and unburnt HC emission decreased with blends B10 and B20 because of high oxygen content. Addition of CERIA21 and CERIA41 in base fuel further reduces CO and HC emissions as cerium oxide promotes complete combustion and proper air fuel mixture in fuels. with B10+CERIA21, B10+CERIA41, B20+CERIA21 and B20+CERIA41 CO emission reduced by 38.88%, 22.22%, 56.25% and 37.5% at CR 16.5 and 25%, 10%, 40% and 30% respectively at CR 13.89 as compared to base fuel. Lowest CO was observed with B20+CERIA at CR16.5 of 0.07% by volume. Least HC was observed with B20+CERIA21 as 69 ppm at full load which was 20.12% less than diesel. At lower CR because of lower heat of compression HC and CO increase.

5. NOx emission increased with B10 and B20 blends than diesel due to higher temperature inside combustion chamber. Addition of CeO_2 in blends further soared NOx emission by reducing ignition delay and increasing flame temperature and exhaust gas temperature. Reduced CR is to reduce the in-cylinder temperatures, and thus flame temperatures during the combustion to suppress NOx emissions. Highest NOx was given by B20+CERIA41 at 744 ppm.

6. Overall performance of engine was improved by adding both different size cerium oxide nanoparticles in B10 and B20. Performance of CERIA21 was slightly better than CERIA41, whereas overall emission was significantly lower for CERIA21 than CERIA41 because of high stability and proper suspension in base fuel.

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