

Effect Of Different Metal Oxide Nano Additives In Jatropha Powered Diesel Engine

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Abstract

The present experimental work reports the working characteristics of single cylinder direct injection diesel engine by adding various metal oxide nano additives such as Aluminum oxide (Al_2O_3), Cerium oxide (CeO_2), Titanium oxide (TiO_2), Copper oxide (CuO) and Zinc oxide (ZnO) into Jatropha Methyl Ester (JME) to assess the performance attributes and exhaust pollutants. The variation of fuel properties and stability of nanoparticles inside JME is examined and compared. The experimental output revealed a perceptible augmentation up to 4.4 and 4.06 % in brake thermal efficiency by the addition of Al_2O_3 and CeO_2 nano additives and substantial reduction in CO, HC, NO and smoke emissions by the addition of Al_2O_3 , CeO_2 and TiO_2 nano additives compared with JME. Conversely, the addition of CuO and ZnO nanoparticles has exhibited a marginal rise in NO emissions. Overall, the Al_2O_3 and CeO_2 nanoparticles have produced better performance output and curtailed pollutants compared to other nanoparticles.

Keywords: nano additives; biodiesel; jatropha; diesel engine; exhaust emissions.

Introduction

In the global context, the fossil fuels hold the major proportion as they are preferred for all modes of transportation. The quest for alternative fuel like biodiesel began due to indiscriminate consumption of fossil fuel reserves, surging fuel costs and adverse environmental impacts caused by the harmful pollutants associated with the use of fossil fuels [1,2]. The vegetable oils are promising fuels as alternative fuels due to their ease of availability and reasonably high cetane number [3]. Among several vegetable oils, the jatropha oil grabs more attention as feedstock in india as it is cultivated throughout the year regardless of climatic conditions [4]. The direct use of vegetable oils in diesel engine is often restrained due to poor atomization owing to high

viscosity [5]. The inclusion of biodiesel in diesel engine also emits excessive NO_x emissions due to their exorbitant oxygen content [6].

The nano sized particles are effective in inducing the diffusion as they spread more evenly within the liquid fuel to enhance the catalytic activity. The catalytic activity of the nanoparticles strongly depends on the particle size and distribution [7-9]. The dispersion of nano additives into liquid fuel like biodiesel enhances the fuel properties like calorific value, flash point etc., [10]. N. R. Banapurmath et al. [11] reported the use of metal nanoparticles such as graphene, multi walled carbon nanotubes and silver nanoparticles in diesel engine and their output exhibited enhanced performance with truncated emission constituents such as CO, HC and smoke. The addition of alumina nano particles into mahua methyl ester results in perceptible reduction of fuel consumption along with slight improvement in thermal efficiency. The nanoparticles enhance the oxidation characteristics by donating the surface lattice oxygen and thereby curtailing the CO and HC emissions. However, escalation of NO_x emissions could be witnessed owing to exorbitant supply of oxygen [12]. A. Prabu et al. [13] attempted to use aluminum and cerium oxide nanoparticles in a mixed proportion in JME and they observed a BTHE close to diesel and significant reduction in pollutants like CO, HC and smoke owing to improved oxidation characteristics by the supply of oxygen from nanoparticles. The nanoparticles are also capable to curtail the NO emissions through scavenging of nitric oxide radical. The use of alumina and CNT in JME is reported by [14]. The results exhibit significant improvement in performance attributes like BTHE and BSFC and drastic reduction in emission constituents like smoke and NO_x because of reduced ignition delay and enhanced ignition properties. The dispersion of cerium oxide and CNT into the blend containing JME and tyre pyrolysis oil (TPO) in various proportions was reported by [15]. The addition of both nano additives enhances the BTHE and minimizes the concentration of pollutants like CO, HC, NO_x and smoke. The cerium oxide supplies the oxygen for the oxidation of CO and absorbs the oxygen for the reduction of NO emissions. The use of copper oxide nanoparticles in mahua biodiesel was reported by [16]. The test output revealed a slight improvement in BTHE along with reduction in HC, CO and smoke emissions and marginal rise in NO_x emissions. An attempt made by [17] to use the titanium oxide nano sized particles in palm oil biodiesel have shown an appreciable depreciation in BSFC, CO, CO₂ and NO_x emissions. The dispersion of zinc oxide nanoparticles into diesel fuel reveals a significant improvement in BTHE and produced higher NO_x emissions compared to

diesel [18]. Vivek W.Khond et al. [19] reviewed the effect of mixing various nano additives in diesel or biodiesel on the working attributes of diesel engine. The nano additives improve the ignition properties through distributed ignition, promotes secondary atomization and higher evaporation rate. The variations of the engine output strongly depend on the characteristics of nanoparticle and vary in different range for each nanoparticle. Therefore, they suggested investigating the catalytic effect of different nano additives in a same base fuel. Hence the present study is devoted to (i) investigate the dispersion stability of various nanoparticles inside same base fuel (JME) (ii) compare the catalytic ability of various metal oxide nano additives such as aluminum oxide, cerium oxide, titanium oxide, copper oxide and zinc oxide inside JME on enhancing the performance attributes and curtailing the deleterious pollutants of diesel engine.

2. Materials and methods

2.1 Materials

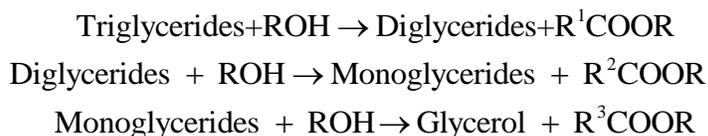
The metal oxide nanoparticles such as Al_2O_3 , CeO_2 , TiO_2 , CuO and ZnO with purity of 99.9% are procured from Nanoshel LLC (USA). The comprehensive specifications of nanoparticles are provided in table 1. The chemicals such as methanol (99%) and KOH (99%) for processing the crude jatropha oil are procured from modern scientific ltd (india). The surfactants such as Span80 and Tween80 are made available from Qualigen chemicals ltd (india).

Table 1 Specifications of nanoparticles

Item	Al_2O_3	CeO_2	TiO_2	CuO	ZnO
Purity (%)	99.9	99.9	99.9	99.9	99.9
Average Particle Size (nm)	20	30-50	3-6	40	3-6
Appearance	White	Milky	White	Black	White
Density (g/cm^3)	3.95-4.1	3.6-4.5	4-4.7	NA	3-4.5
Molecular weight (g/mol)	101.96	NA	NA	79.545	80.264
Specific Surface area (m^2/g)	15-20	10-18	10-16	>13	15-20

2.2 Fuel blends preparation

The crude jatropha oil procured from the local market and transesterified using base catalysts (1 wt. % of KOH) with an oil to methanol ratio of 6:1 at a reaction temperature of at 60°C for 1 hour to produce its methyl ester (JME). During this process, the molecules of JO are chemically broken into methyl esters and separated as depicted in fig 1(a) & (b). The conversion process of crude JO into JME is given by the following equation:



The nanoparticles are environmentally reactive owing to its high surface area to volume ratio. Hence, the handling of nanoparticles while dispersing into liquid fuel must be carried out without reacting with environment. The homogeneous suspension of metal oxide nano additives into JME along with a surfactant of Span80 and Tween80 is performed using an Ultrasonic vibrator (make: Hielscher, Model: UP400S) for 30 minutes with a frequency of 40 kHz, 120W as depicted in fig 2. The longer stability of nanoparticles inside JME is an essential factor for commercialization and utilization as alternative fuel in diesel engine for transport applications. The nanoparticles with smaller particle size are found to be more stable inside JME when compared with larger size nanoparticles [20]. The potential difference between base fuel (JME) and dispersing medium (nanoparticles) plays a vigorous role in maintaining the stability. The results of dispersion stability of each nanoparticle inside JME are provided in table 2.



Figure 1 Biodiesel preparation (a) stirring (b) separation



Figure 2 Dispersion of nanoparticles using Ultrasonicator

Table 2 Stability results of nanoparticles

Nanoparticle	surfactant used	Stability duration
Al ₂ O ₃	Span 80 and Tween80	8 days
CeO ₂	Span 80 and Tween80	10 days
TiO ₂	Span 80 and Tween80	5 days
CuO	Span 80 and Tween80	8 hours
ZnO	Span 80 and Tween80	11 hours

Table 3 Properties comparison of test fuel blends

Item	ASTM std.	JME	JME+ Al	JME+ Ce	JME+ Ti	JME+ Cu	JME+ Zn
Density (kg/m ₃)	D1298	890	890.4	890.2	890.8	891	890.6
Kinematic viscosity at 40°C(cSt)	D445	5.20	5.24	5.24	5.25	5.22	5.23
Flash point (°C)	D93	82	78	79	79	80	80
Calorific value (MJ/kg)	D240	39	40.2	40.1	39.9	39.8	39.6
Cetane no.	D613	53	55	54	55	54	55

The property variations after mixing various nano additives into JME is measured and compared with JME as presented in table 3. The density and kinematic viscosity of test fuels are measured using hydrometer and redwood viscometer respectively. The flash point was measured by Pensky-Martins closed cup apparatus. The calorific value and cetane number is measured using bomb calorimeter and ignition quality tester respectively.

2.3 Experimental setup and conditions

The variation of engine performance attributes and exhaust pollutants were studied on a single cylinder, four stroke, water cooled compression ignition engine as specified in table 4. As depicted in fig 3, the panel box comprises of fuel tank, air box, fuel and water flow measuring units and digital display units. All engine tests were conducted by varying the load using eddy current dynamometer at a constant speed of 1500 rpm. Initially the tests are performed with pure JME by varying the load. The engine is operated until the entire consumption of JME before dosing the nano additives. The performance attributes such as BTHE and BSFC are measured using labview based engine analysis software “EnginesoftLV”. Each test is repeated for three consecutive cycles under identical conditions and the repeatability of all test results are found to be within 3%. The exhaust pollutants such as CO and HC are measured on dry basis and NO emissions are measured using chemiluminescence method using a chemical sensor in the four gas emission analyzer (make: HEPHZIBAH) and the smoke opacity is quantified from smoke meter (make: AVL) using optics based folded geometry. The exhaust gas temperature is measured using chromelalumel (K-type) RTD make PT 100 type thermocouple. The uncertainty analysis of various measuring instruments is given in table 5.

Table 4 Engine Configurations

Parameter	Specification
Type of Engine	Kirloskar (Model: 240PE) Single Cylinder Variable Compression Ratio DI Diesel Engine.
Bore & Stroke	87.5 × 100mm
Compression ratio range	12 to 18
Cubic capacity	0.661 liters
Fuel Injection timing	23 ⁰ BTDC

Rated power	3.5 KW @ 1500rpm
Injection pressure	210 bar
Piezo sensor Range	Up to 350bar Pressure
Crank angle encoder	Resolution of 1 Deg, Speed of 5500 RPM with TDC pulse
ECU	PE3 Series ECU, Model PE3-8400P
Temperature	K-type Thermocouple
Type of Cooling	Water cooled
Type of Loading	Eddy Current Dynamometer with water cooling

Table 5 Uncertainty analysis of the measuring instruments

Instrument	Type and manufacturer	Measuring Range	Accuracy	% of Uncertainty
Exhaust gas analyzer	HG-540 & HEPHZIBAH	CO-0-9.999 %	0.001 %	0.5
		HC-0-15000 ppm	1 ppm	1
		NO- 0-10000 ppm	3 ppm	1
Smoke meter	AVL	0-100%	±0.1	1
Temperature sensors	RTD PT100 type K thermocouple	0-1200 °C	±1 °C	2



Figure 3 Experimental setup

3. Results and Discussions

The operation of the engine is found to be smooth during the entire testing conditions. In this section variations of performance attributes and exhaust pollutants are discussed.

3.1 Performance Characteristics

Fig 4 illustrates the variation of brake thermal efficiency under brake mean effective pressure for various fuel blends. The improvement in BTHE is found to be more significant (up to 7.85 and 7.61%) by the addition of Al_2O_3 and CeO_2 nanoparticles. The enhancement in heating value by the dosage of both Al_2O_3 and CeO_2 nanoparticles results in improved heat release favoring better energy conversion. These nanoparticles are capable to maintain the surfaces highly active owing to enhanced catalytic activity and promote better combustion. The enhancement in surface area improves the reactivity between fuel and air to enhance the BTHE [9]. However, the improvement in BTHE is found less significant (up to 5.77, 5.03 and 3.98%) for TiO_2 , CuO and ZnO nanoparticles. It is evident from the results, the catalytic ability of these nanoparticles are poor when dispersed into JME to enhance the performance characteristics. The variation of brake specific fuel consumption with respect to bmep is depicted in fig 5. The reduction in BSFC was found more significant (up to 10.68 and 8.44%) for Al_2O_3 and CeO_2 nanoparticles. The engine is

able to generate adequate power owing to enhanced properties like cetane number, calorific value by consuming less fuel. However, the reduction is found less significant (up to 5.64, 4.90 and 2.34%) for TiO₂, CuO and ZnO nanoparticles attributable to their poor catalytic ability for efficient energy conversion with less fuel consumption.

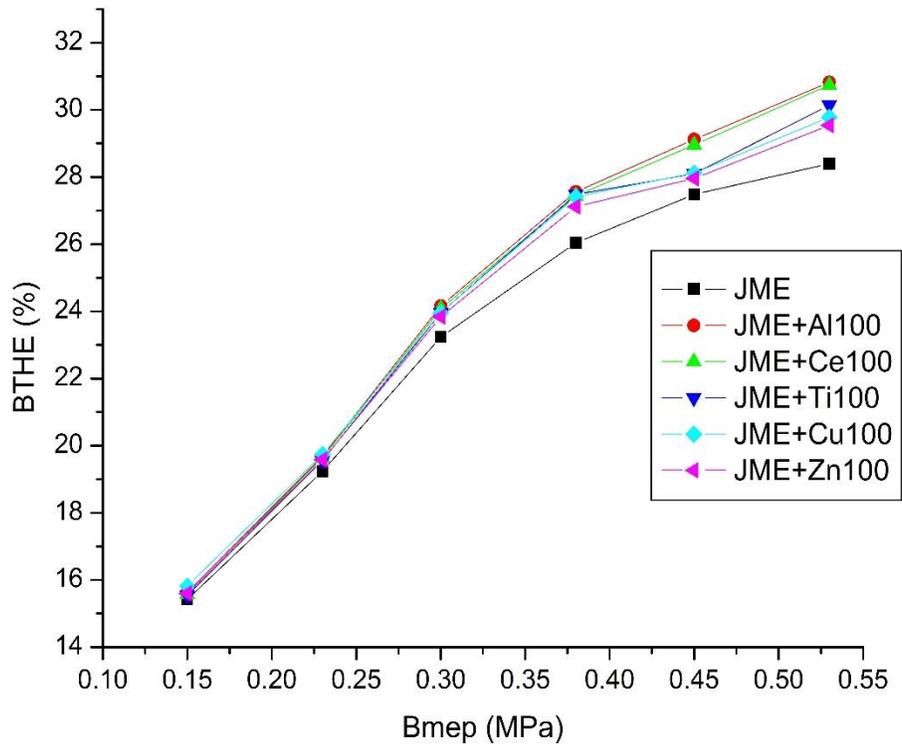


Figure 4 Variation of BTHE for various nanoparticles

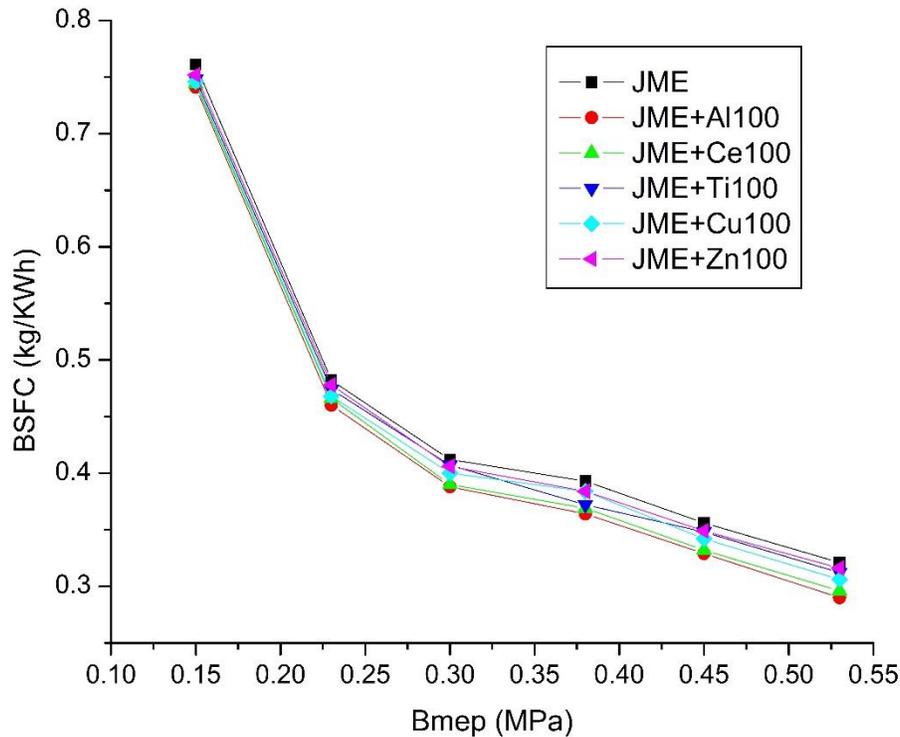


Figure 5 Variation of BSFC for various nanoparticles

3.2 Emission characteristics

The % of variation of CO emissions with respect to bmeep is illustrated in fig 6. With an increase in load, the concentration of CO emission decreases under all test fuel blends owing to improved oxidation characteristics. The inclusion of metal oxide nano additives into biodiesel enhances the mobility of oxygen which improves the oxidation of carbon promoting near complete combustion. The CO emissions reduced more significantly (up to 79.31, 72.97, and 67.74%) by the addition of CeO₂, TiO₂ and Al₂O₃ nano particles respectively. Therefore, it is evident from the results, the oxidation potential of these nanoparticles to convert CO into CO₂ is high whereas marginal reduction of CO emissions (up to 26.82 and 23.8%) by ZnO and CuO nanoparticles exhibits their poor oxidation ability.

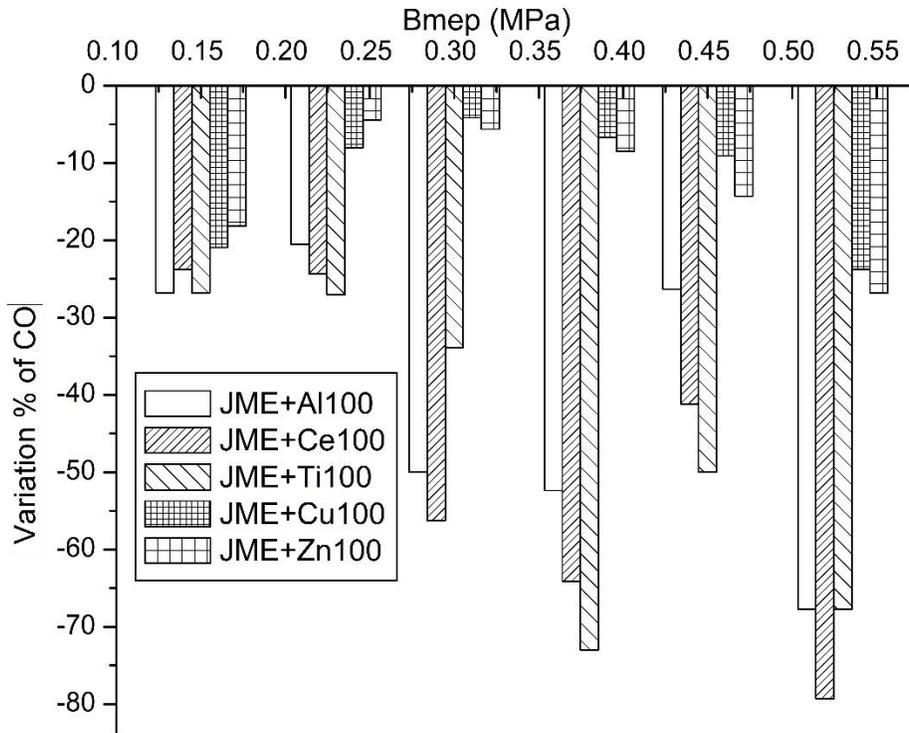


Figure 6 Variation of CO emissions for various nanoparticles

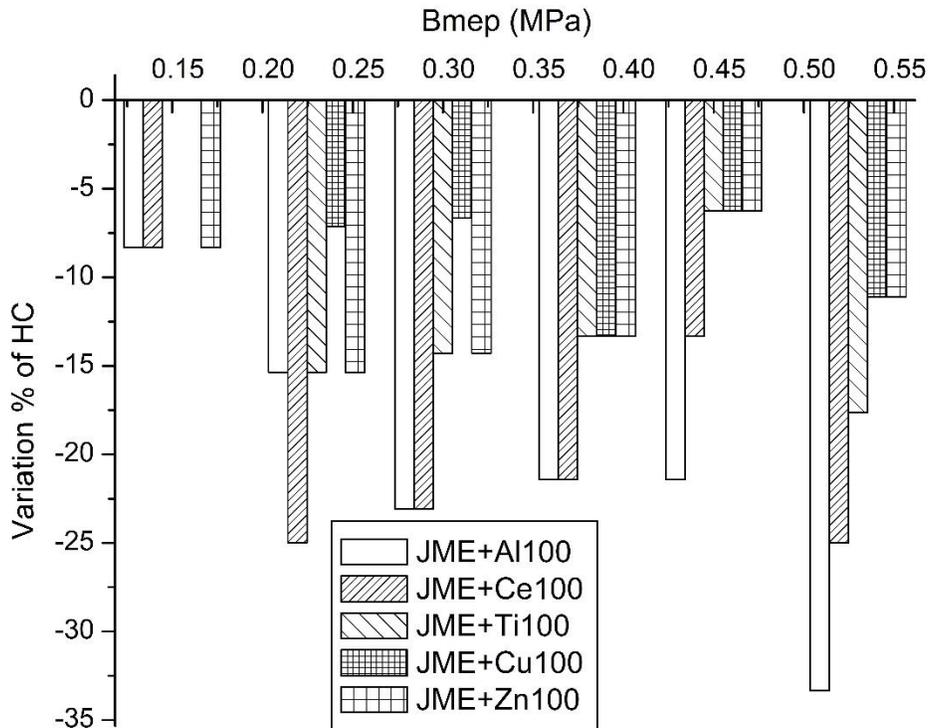


Figure 7 Variation of HC emissions for various nanoparticles

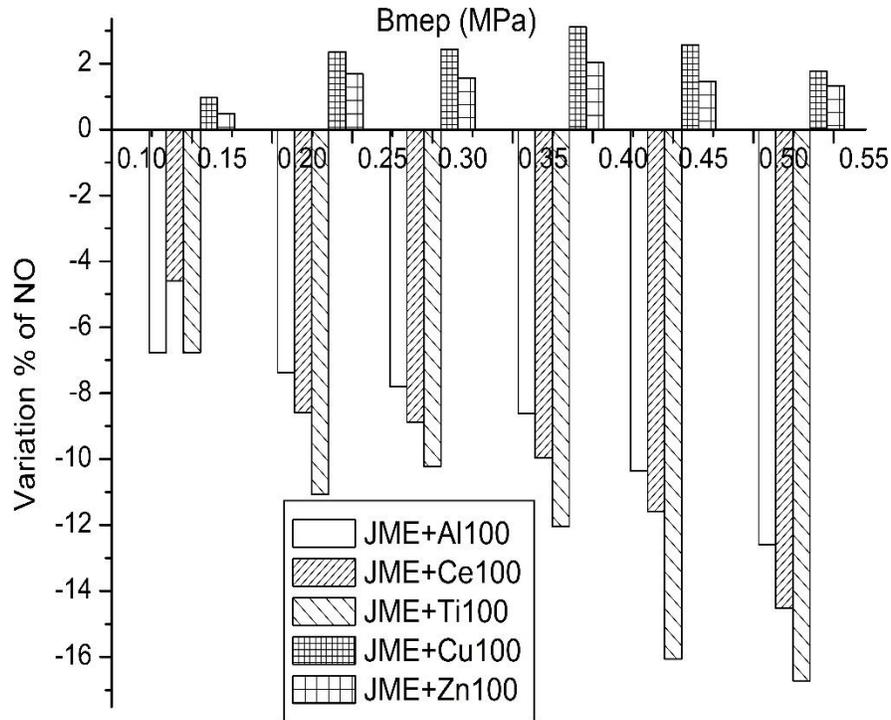


Figure 8 Variation of NO emissions for various nanoparticles

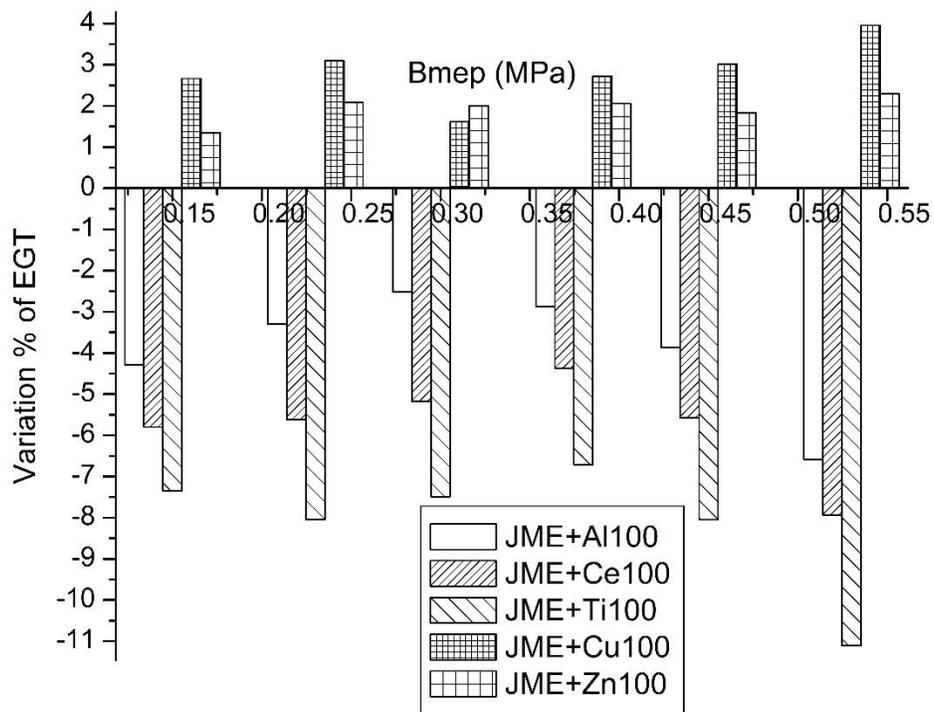


Figure 9 Variation of EGT for various nanoparticles

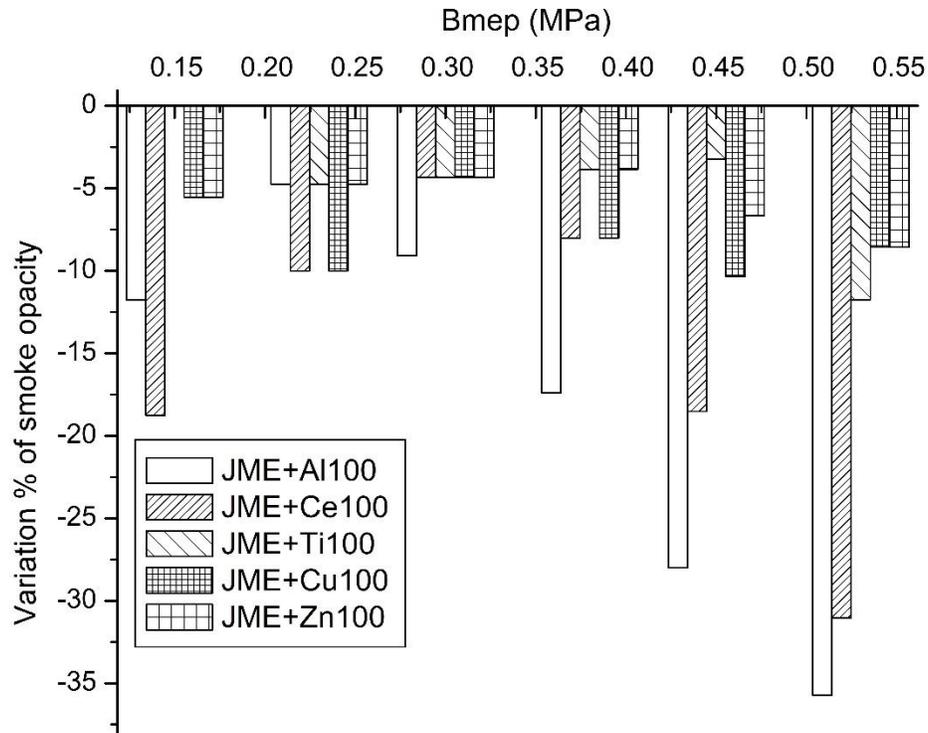
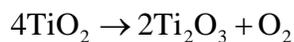
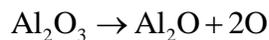
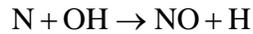
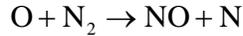


Figure 10 Variation of smoke opacity for various nanoparticles

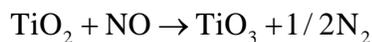
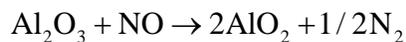
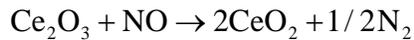
The % of variation of HC emissions under bmep is shown in fig 7. The addition of Al_2O_3 and CeO_2 nanoparticles into JME makes substantial contribution in minimizing the HC emissions (up to 33.33 and 23.07%). The exorbitant supply of oxygen by these nanoparticles oxidizes the hydrocarbons and favoring better combustion. The presence of these nanoparticles distributes the fuel significantly resulting in minimized unburnt mixture¹⁵. The marginal declines of HC emissions (up to 17.64, 13.33 and 15.38%) for TiO_2 , CuO and ZnO nanoparticles shows their poor ability to oxidize the unburnt hydrocarbons. The supply of oxygen by the nanoparticles for achieving the near complete combustion is given by the following equations:



The % of variation of NO emission with respect to varying Bmep for JME with various metal oxide nano additives compared to JME is illustrated in fig 8. The mechanism behind formation of NO is given by equation (3).



The increase in load causes the NO concentration to rise for all fuel blends. The addition of aluminum, cerium and titanium oxide nanoparticles slightly minimizes the NO emissions up to 12.6, 14.52 and 16.72% respectively. The reduction could be attributed to improved catalytic activity and scavenging of nitric oxide radical [13]. The nanoparticles are potential in absorbing the oxygen for the reduction of NO emissions [15]. However, the addition of zinc and copper oxide nanoparticle into JME produced negative effect and marginally increases the NO emissions up to 2.03 and 3.1% respectively. The following equation shows the mechanism of oxygen adsorption by nanoparticles to minimize the concentration of NO emissions.



The % of variation of EGT with respect to varying Bmep for JME with various metal oxide nano additives compared to JME is shown in fig 9. With an increase in load the EGT increases sharply as the combustion takes place at higher temperature. The variations of EGT have shown similar variation trends of NO emissions. The addition of aluminum, cerium and titanium oxide marginally reduces the EGT up to 6.58, 7.93 and 11.1 % and the addition of copper and zinc oxide nanoparticles increases the EGT up to 3.95 and 2.29% respectively.

The % of variation of smoke opacity with respect to varying Bmep for JME with various metal oxide nano additives compared to JME is shown in fig 10. By the increase of load, the smoke opacity increases under all fuel blends. The addition of aluminum and cerium oxide nanoparticles has shown perceptible decrement of 35.7 and 31.03% of smoke emissions. This could be probably attributed to rapid evaporation and improved ignition characteristics causing near complete combustion [14]. The addition of titanium, copper and zinc oxide nanoparticles exhibited marginal decline up to 11.76, 10.34 and 8.57% respectively.

4. Conclusion

A single cylinder direct injection CI engine was experimentally investigated while fueled with pure JME, JME with various nanoparticles. The primary conclusions of this study can be summarized as follows:

- The stability of Al_2O_3 , CeO_2 and TiO_2 nanoparticles was found more than 5 days. However, the CuO and ZnO nanoparticles were separated from biodiesel within 8 and 11 hours respectively.
- The addition of all nanoparticles exhibits a significant improvement in BTHE. The improvement of BTHE varies from 2.5 to 4.4% and reduction in BSFC varies from 6.7 to 1.5%. The best and least improvements could be witnessed for Aluminum and zinc oxide nanoparticles.
- The reduction of CO emissions was found better up to 40.6, 48.1 and 46.4% for Al_2O_3 , CeO_2 and TiO_2 nanoparticles when compared with marginal reduction of 12.1 and 12.9% for CuO and ZnO nanoparticles.
- The reduction of HC emissions was found better up to 20.4 and 19.3% for Al_2O_3 and CeO_2 nanoparticles when compared with 11.1, 7.4 and 11.4% for TiO_2 , CuO and ZnO nanoparticles.
- The NO emissions decreased up to 8.9, 9.6 and 12.1 % for Al_2O_3 , CeO_2 and TiO_2 nanoparticles and marginally raised up to 2.2 and 1.4% for CuO and ZnO nanoparticles.
- The smoke emissions drastically reduced up to 17.7 and 15.1% for Al_2O_3 and CeO_2 nanoparticles and slight reduction could be witnessed up to 4.6, 7.8 and 5.6% for TiO_2 , CuO and ZnO nanoparticles.
- Overall, the enhancement of engine output characteristics and minimization of deleterious pollutants was found to be better for Al_2O_3 and CeO_2 nanoparticles comparing with all other nanoparticles.

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