University of Baghdad
College of Engineering
JOURNAL OF ENGINEERING

Journal of Engineering
journal homepage: www.joe.uobaghdad.edu.iq
Number 4 Volume 28 April 2022

Chemical, Petroleum and Environmental Engineering

Improvement of Diesel Fuel Engine Performance by Nanoparticles Additives

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ABSTRACT

This study was done to investigate the impact of different nanoparticles on diesel fuel characteristics, Iraqi diesel fuel was supplied from al-Dura refinery and was treated to enhance performance by improving its characteristics. Two types of nanoparticles were mixed with Iraqi diesel fuel at various weight fractions of 30, 60, 90, and 120 ppm. The diesel engine was tested and run at a constant speed of 1600 rpm to examine and evaluate the engine's performance and determine emissions. In general, ZnO additives' performance analysis showed they are more efficient for diesel fuel engines than CeO. The performance of engine diesel fuel tests showed that the weight fraction of nanoparticles at 90 and 120 ppm give a similar performance, so, for economic aspects, the additives at 90 ppm of two types of nanoparticles gave good performance efficiency and the best reduction of gas emissions. The enhancement for ZnO additives is up to 34.28% compared to pure diesel fuel, while for nano CeO, the maximum enhancement is 20% compared to pure diesel fuel. The brake thermal efficiency increases with additives. The best improvements in brake thermal efficiency were 62% for ZnO and 59% for CeO, respectively, both at 120 ppm. A reduction in NOx, CO_2, CO and UHC emissions was observed compared with the diesel fuel that was consumed from pure diesel fuel. The maximum reduction emissions values for NOx, CO, CO_2 and un-burn hydrocarbon (UHC) were 63.77, 29.26, 56.41, and 57.37 % for ZnO, and 58.11, 37.80, 61.53, and 50.81 % for CeO additives. Therefore, it is recommended to utilize nanoparticles, especially ZnO, as a fuel additive with diesel fuel and consider them as an enhancer material to increase engine efficiency and reduce exhaust emissions.

Keywords: Diesel engines, exhaust emissions, nanoparticles in fuel engines

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2022.04.06

Article received: 7/1/2022
Article accepted: 1/3/2022
Article published: 1/4/ 2022

تحسين أداء وقود محرك الديزل بواسطة مضافات الجسيمات النانوية

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الخلاصة

أجريت هذه الدراسة للتحقيق وفحص تأثير الجسيمات النانوية المختلفة على خصائص وقود الديزل ، حيث تم توفير وقود الديزل العراقي من مصفاة الدورة وتمت معالجته لتحسين الأداء من خلال تحسين خصائصه. تم خلط نوعين من الجسيمات النانوية (أكسيد السيريوم ، CeO وأكسيد الزنك ، ZnO) مع وقود الديزل العراقي بأجزاء وزن مختلفة من 30 ، 60 ، 90 ، 120 جزء في المليون. تم اختبار أداء محرك الديزل وتشغيله بسرعة ثابتة تبلغ 1600 دورة في الدقيقة لفحص وتقييم أداء المحرك وقياس الانبعاثات. بشكل عام ، أظهر تحليل أداء إضافات ZnO أنها أكثر كفاءة لمحركات وقود الديزل من CeO. أظهر أداء اختبارات وقود الديزل للمحرك أن الكسر الوزني للجسيمات النانوية عند 90 و 120 جزء في المليون له أداء متقارب، لذلك ، بالنسبة للجوانب الاقتصادية ، فإن المواد المضافة عند 90 جزء في المليون لنوعين من الجسيمات النانوية أعطت كفاءة أداء جيدة وأفضل تقليل لانبعاثات الغازات. يصل التحسين لمضافات ZnO إلى 34.28٪ مقارنة بوقود الديزل النقي ، بينما بالنسبة للنانو CeO ، فإن الحد الأقصى للتحسين هو 20٪ مقارنة بوقود الديزل النقي. تزداد الكفاءة الحرارية للفرامل مع الإضافات. كانت أفضل التحسينات في الكفاءة الحرارية للفرامل هي 62٪ و 59٪ لـ ZnO و CeO ، على التوالي ، عند 120 جزء في المليون. لوحظ انخفاض في انبعاثات أكاسيد النيتروجين وأول أكسيد الكربون وثاني أكسيد الكربون والمركبات الهايدروكاربونية الغير محترقة مقارنة بوقود الديزل الذي تم استهلاكه من وقود الديزل النقي. كانت قيم الحد الأقصى لخفض الانبعاثات لأكاسيد النيتروجين ، وأول أكسيد الكربون ، وثاني أكسيد الكربون ، وUHC 63.77 ، و 29.26 ، و 56.41 ، و 57.37٪ لـ ZnO ، و 58.11 ، و 37.80 ، و 61.53 ، و 50.81٪ لإضافات CeO. لذلك ، يوصى باستخدام الجسيمات النانوية ، وخاصة ZnO ، كمادة مضافة للوقود مع وقود الديزل ، واعتبارها مادة محسّنة لزيادة كفاءة المحرك وتقليل انبعاثات العادم.

INTRODUCTION

The need for energy resources, especially fossil fuels, has been increasing day by day due to the increasing population across the globe and the machines that use the diesel engine, which has led to the exhaustion of fossil fuel pollutants and their environmental effects. There have been a number of research attempts to replace fossil fuels with renewable energy sources in order to reduce environmental damage and provide easily renewable fuels for use in internal combustion engines **(Verma, et al.,2018)**.Climate change and global warming are the world's most pressing issues today, as well as the greatest challenge for governments and scientists in the twenty-first century. The average temperature of the Earth has risen by about 0.6 °C every decade **(Khalife, et al.,2017)**. Many countries in the world have begun to regulate and control pollution and have made plans for this purpose. For example, in the USA, sulphur dioxide emissions were reduced and declined by 30% from 1970 to 1992. In Iraq, where there are some difficulties and some problems, there is serious legislation or regulation framework for restrictions or using advanced technology for treatment of environmental waste or emissions **(Abdullah, et al.,2018)**. Control of emission gases like SOx and NOx by clean air legislation is leading to an enhancement in air quality, so environmental policy should be imposed on different industries and commercial activities to achieve this target **(Gan, 2012, Mohammed, 2011).**

The addition of nanoparticles to diesel fuel can improve engine performance by lowering greenhouse gas emissions, particularly CO, NO_X, and HC compounds **(Mahendravarman, et al.,2016)**.A number of researchers are interested in investigating the effects of nanoparticle additives to various types of fuels on their characteristics and performance efficiency **(Kogej, 2011).**

For reducing the ignition delay and cylinder pressure with and at higher engine loads, nano-fuel additives were used. Aluminum nanoparticle addition decreased the specific fuel consumption and the neat diesel fuel. Also, the emissions of HC and CO were reduced at higher engine loads **(Ghanbari, 2008).**

Jung et al. **(Jung, et al.,2005)** studied the effects of nanoparticles additive on emissions, combustion, and flame and also studied the kinetics of oxidation in diesel engines. The study shows that with the use of increasing amount of nanoparticles in diesel and biodiesel engines, the brake specific fuel consumption decreased while engine speeds, torque, and power increased.

Ghanbari **(Ghanbari, et al., 2017)** studied the influence of Ag nanoparticles and carbon nanotubes (CNT) on the exhaust gas emissions. The emissions of CO_2 and NOx decreased and emissions of CO and HC increased by using nano additives in diesel and biodiesel blend fuels.

Mehta et al. **(Mehta, et al., 2014)** show that the performance and emissions when adding nanoparticles of aluminum, boron, and iron to base diesel fuel cause rapid oxidation, delay, and complete combustion and short ignition. Furthermore, they improve the combustion rate and reduce ignition delay. The brake thermal efficiency increases by 4%, 9%, and 2% for iron, aluminum, and boron in diesel fuel, respectively.

Tyagi et al **(Tyagi, et al., 2008)** show the rise in NO_X gas emissions compared to pure diesel oil, and this certainly causes greenhouse effects and climate change and it's a negative effect to the environment. This occurs because of the increment in cylinder combustion temperature.

Karthikeyan et al. **(Karthikeyan, et al., 2014)** investigated the effect of zinc oxide (ZnO) nanoparticles added to canola oil methyl ester on fuel engine performance and exhaust emission gas characteristics, using doses of 50 and 100 ppm of ZnO. The observed results of this study show that the calorific value and kinematic viscosity for D80 B20 ZnO 50 ppm and D80 B20 ZnO 100 ppm have increased compared with B20, decreasing the ignition time delay when ZnO additives are added to the fuels, reducing the brake specific fuel consumption measurement and increasing the brake thermal efficiency for the nanoparticle additives to B20.

The present study focused on investigating the effects of two types of nanoparticles on the combustion performance and emission characteristics of diesel engines. Metal oxide nanoparticles of cerium oxide (CeO) and zinc oxide (ZnO) were used as fuel additives in diesel fuel combustion engines to investigate their effect on diesel fuel characteristic efficiency ,break thermal efficiency, and its emission. Because of their catalytic reactivity, nano particles can enhance engine performance and reduce emissions because of their catalytic reactivity compared to fuel blends **(Ramesh, et al., 2018)**.

2. EXPERIMANTAL WORK

2.1 Materials

2.1.1 Feedstock

Iraqi diesel fuel was used in this study, which was supplied from al-Durra refinery. **Table 1** shows the characteristics of diesel fuel.

Table 1. The properties of Iraqi diesel fuel

Characteristics	value
Specific gravity at 15.6/15.6 ^{0}C	0.87
API gravity at 15.6 ^{0}C	35.7
Viscosity, c.st.at 40 ^{0}C	3.268
Sulfur content, wt.%	1.424
Flash point ^{0}C	71.4
Calorific value(kJ/kg)	24800

Color	0.5
Pour point ^{0}C	-9
Aniline point ^{0}C	72.1
Cetane number	58.2
Carbon Residue wt. %	0.17

2.1.2 Nanomaterials

Two types of nanoparticles additives were used in this study (CeO and ZnO), cerium oxide CuO was supplied by (Alpha Chemika, India) and zinc oxide ZnO was supplied by (Hongwu International Group Ltd., Guangdong, China). The properties and analysis of two nanoparticles are shown in **table 2**.

Table 2. Nanoparticles properties.

Property	CeO	ZnO
Purity, %	99	99+
average particles size distribution, nm	70	40
Color	Brown	White
Specific heat capacity, J/(g. ^{0}C)	106.47	0.494
Density, Kg/m^3	7600	5600
Surface area, m^2/g	55	91
Pore volume, cm^3/g	0.0148	0.68
Melting point, ^{0}C	2340	1974
Solubility in water, %	Insoluble	0.0004

2.2 Experimental engine setup

The experiments in this research were performed on a Fiat engine with four cylinders, a four-stroke diesel engine, engine model TD 313, naturally aspirated and water cooled. Engine speeds varied in the range of 800-1900 rpm, and a coupled dynamometer was used in the research. Fuel emissions were measured by using a Multi-Gas Model 4880 Analyzer for measuring the concentration of emission gases (NOx, CO, CO_2, and UHC). **Table 3** describes the specifications of the diesel engine.

Table 3. Specifications for fuel diesel engines.

Characteristics	value

Displacement volume	3.666 L
Compression ratio	17
Valve /cylinder	2
Stroke	110 mm
Bore	100 mm
Nozzle hole diameter	0.48mm
Spray angle	160^o
Unit pump diameter plunger	26 mm
Nozzle opening pressure	40Mpa

In **Fig. 1** schematic of Fiat engine is shown. The first nanoparticle additives were added in various weight fractions of 30, 60, 90, and 120 ppm to diesel fuel,
The nanoparticles dose was chosen to be 25, 50, 100 and 150 ppm. The mass of nanoparticles required for each dose is calculated using Eq. (1) **(Nasir, 2018)**.

$$\emptyset = \frac{\frac{mp}{\rho p}}{\frac{mp}{\rho p}+\frac{mf}{\rho f}} \qquad (1)$$

and then tested in a laboratory diesel engine to study and evaluate its performance and gas emission levels.

Figure 1. The schematic of a Fiat diesel engine.

3. RESULT AND DISCUSSION

3.1 Diesel engine performance

3.1.1 Brake Specific Fuel Consumption (BSFC) measurement

Fig. 2 shows the effect of pure diesel fuel and different doses of nanoparticles in ppm on the brake specific fuel consumption (BSFC) at 1600 rpm engine speed. The graph shows that the addition of nanoparticles reduces the specific fuel consumption for two nanoparticles at any dose at all speeds. This may be due to the fact that the increasing dose of nanoparticles leads to an increase in lower calorific value (LCV), especially for ZnO nanoparticles, which gave more performance efficiency in engine fuel consumption compared with CeO nanoparticles, and the best dose of nanoparticles was 30 ppm. The nanoparticles play an important role with oxygen in making the combustion process complete and releasing the maximum possible heat **(Karthikeyan, et al., 2017)**. The BSFC of ZnO is less than CeO at all speeds, especially at 30 ppm, and this represents a suitable amount of oxygen that makes a complete combustion in 30 ppm blends **(Syed, et al., 2015)**. The maximum reduction in the increase in the BSFC was 34.28% for ZnO and 20% for CeO at 30 ppm for two types of nanoparticles as a reference with pure diesel fuel at a speed of 1600 rpm, and this result is in agreement with the study of Selvaganapthy **(Selvaganapthy, et al., 2013)**.

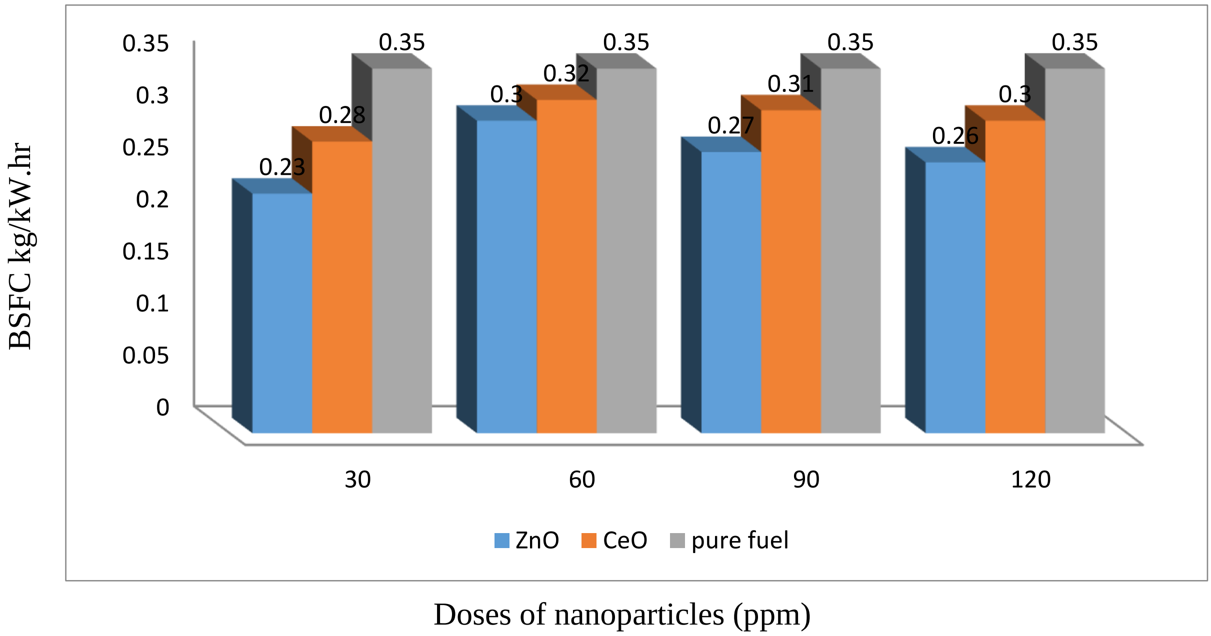

Figure 2. The effect of pure diesel fuel and nanoparticles additives to the (BSFC) .

3.1.2 Brake Thermal Efficiency η_{bth}

The brake thermal efficiency is the kind of engine thermal efficiency which is the ratio of the brake power at the engine crankshaft to the power generated by the combustion of the fuel. The brake thermal efficiency shows the amount of power taken by the engine crankshaft out of total power generated by the combustion of the fuel.

the fuel consumption can be
determined by the following Eq. (2) **(Chaven and Pathak, 2008).**

$$mf = \frac{Sgf \times 8 \times 0.001}{t} 3600 \quad (2)$$

Where :

mf = Fuel Consumption (kg/hr).
Sgf = specific gravity of the fuel (kg/L).

Thus, specific fuel consumption can be obtained by the Eq.(3) **(Jain and Rai,2010)** :The brake thermal efficiency for the engine is given by,

$$BSFC = \frac{mf}{Bf} \quad (3)$$

Where :
BSFC = Brake Specific Fuel Consumption (kg/kW.hr).
BP = Brake Power (kW).
mf = Fuel Consumption (kg/hr)

Brake thermal efficiency is a measure of the fuel efficiency of internal combustion engines. The higher the brake thermal efficiency, the lower the fuel consumption, and greenhouse gas emissions .**Fig. 3** shows the effect of pure diesel fuel and nanoparticle doses on brake thermal efficiency, ηbth, The figure shows that the thermal efficiency of the brake increases with nanoparticle addition for all doses due to improved fuel combustion, which results in an increasing surface-to-volume ratio **(Sajith, et al., 2010)**. The best dose quantity has been obtained with 120 ppm for two nanoparticle types. The maximum percent of brake thermal efficiency is 62% for ZnO and 59% for CeO, and these values of the brake thermal efficiency are because the nanoparticles additives reduce the evaporation period and, thus, ignition delay is reduced, so high rate mass transfer causes ignition time delay **(Soner, et al., 2016)**.

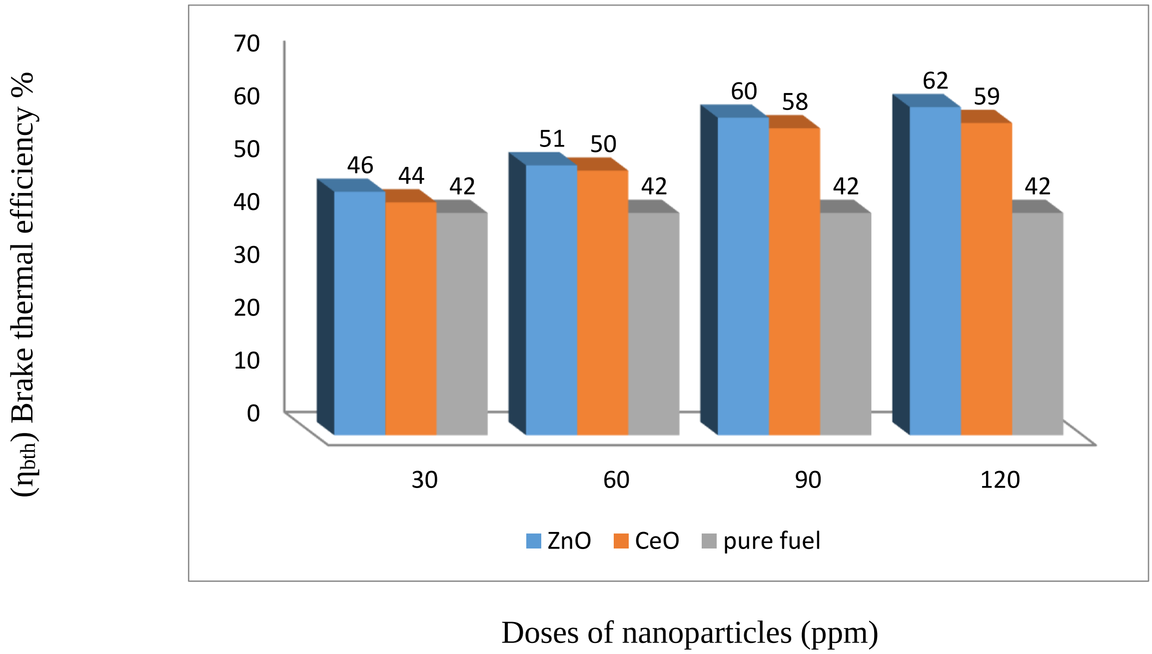

Figure 3. The effect of pure diesel fuel and nanoparticles additives on the thermal efficiency percentage.

3.2 Gaseous Emissions

This part of the study presents the effects of nanoparticle doses on different gas emissions:

3.2.1 Nitrogen oxide emissions (NOx)

Fig. 4 presents the effect of pure diesel fuel and nanoparticle additive doses on the NOx emission. From the figure, it can be notice that a doses of 30 and 60 ppm, the NOx where of same level, while at 90 ppm it decreases a little, and sharply decrease at 120 ppm. Also, it was observed that the nitrogen oxide (NOx) emission for pure diesel fuel was approximate or slightly less than the other ratio of diesel blends at low concentrations of nanoparticles. These results are in agreement with the results obtained by Ajin **(Ajin, et al., 2013)**.

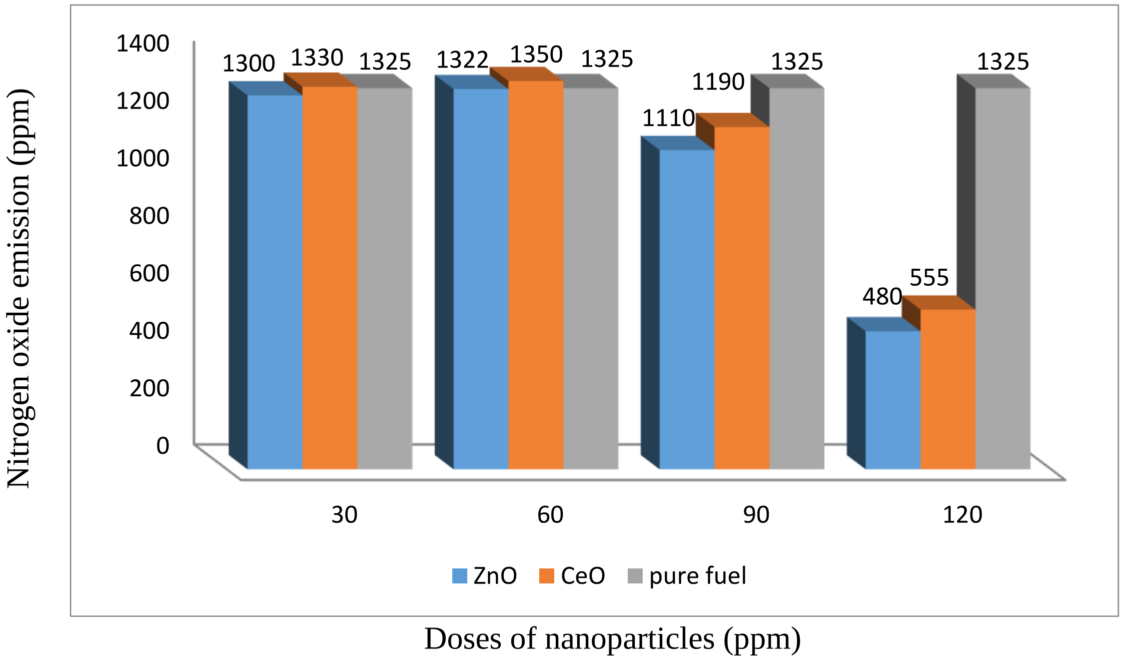

Figure 4. The effect of pure diesel fuel and nanoparticles additives on the nitrogen oxide emission

3.2.2 Carbon monoxide emissions (CO)

Fig. 5 present the effect of pure diesel fuel and nanoparticles additives doses on the CO emissions, the figure show that adding nanoparticles additives leads to decrease in CO gas emissions for all nanoparticles doses compared with the pure diesel fuel, this is because of shorter delay period when adding nanoparticles and this is certainly leads to complete combustion **(Ramesh, et al., 2015)**. The best results of reduction in CO gas emission occurred with 120 ppm of nanoparticles dose, these value was 29.26 % for ZnO and 37.80% for CeO. For all doses level, the CeO was of better reduction of Co emission, the reduction in CO gas emission indicate to complete combustion of blending diesel fuel with nanoparticles **(Sajith, et al., 2015)**.

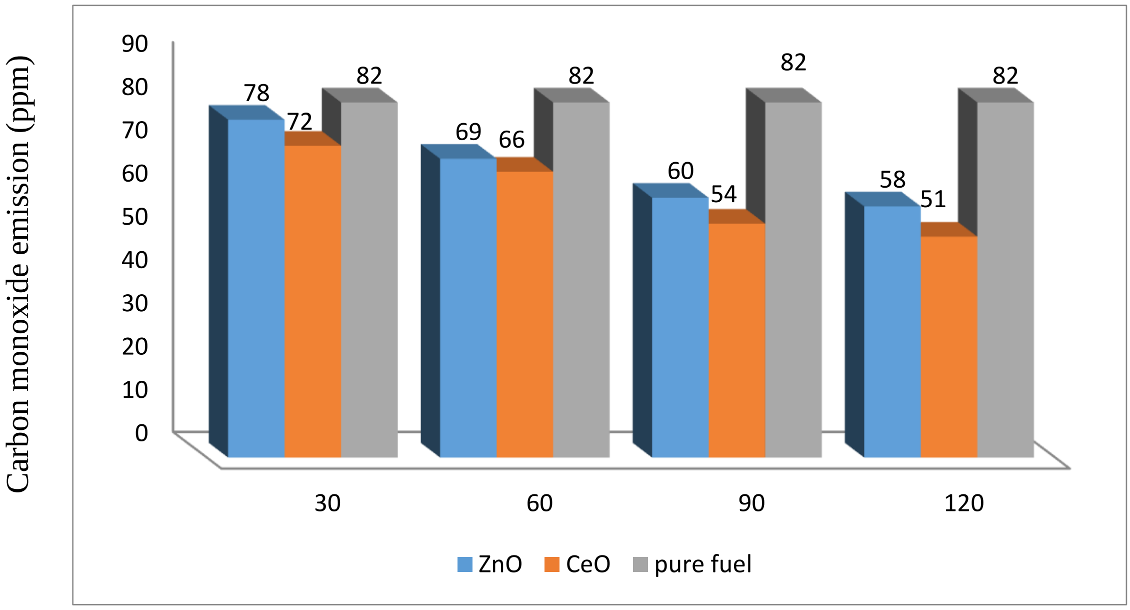

Figure 5. The effect of pure diesel fuel and nanoparticles additives on the carbon monoxide emission

3.2.3 Carbon Dioxide Emissions (CO_2)

Fig. 6 presents the effect of pure diesel fuel and nanoparticles doses on carbon dioxide CO_2 emissions. The figure shows that, in general, nanoparticles additives decrease the CO_2 emissions, and when increasing the amount of nanoparticles, the performance of nanoparticles for reduction of CO_2 emissions may be due to oxygen atoms whose presence in nanoparticles leads to complete combustion **(Heydari-Maleney, et al., 2015)**.. This is also due to the fact that the quantity of CO_2 emissions depends on the ratio of air to diesel fuel **(Al-Hasan, et al., 2003 and Wu, et al., 2004).** The figure also shows that the maximum reduction of gas emissions occurred at 90 ppm, 61.53 % for CeO and 56.41 % at 60 ppm for ZnO.

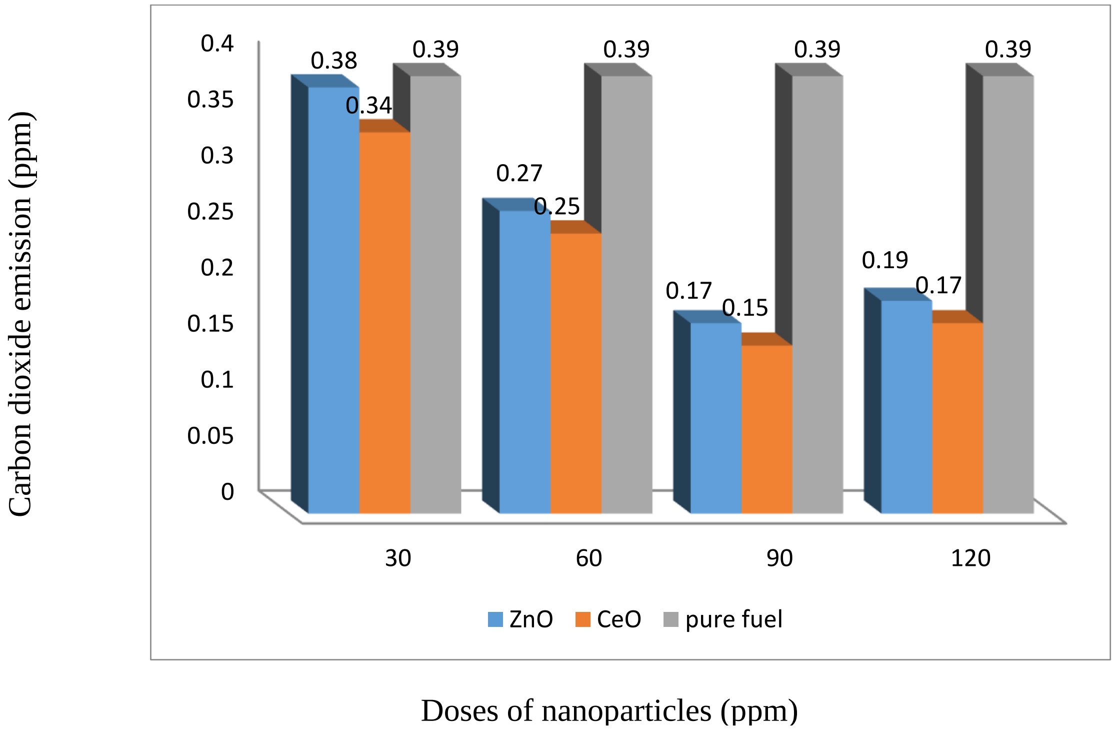

Figure 6. The effect of pure diesel fuel and nanoparticles additives on the carbon dioxide emission.

3.2.4 Un-burn Hydrocarbon UHC Emissions

Fig.7 presents the effect of pure diesel fuel and nanoparticle doses on un-burned hydrocarbon (UHC) emissions. The figure shows that the UHC emissions decrease by nanoparticle additives for all doses. Because of incomplete combustion of diesel fuel, emissions of unburned hydrocarbons (UHC) occurred.

Incomplete combustion occurred because of incomplete/distorted flame propagation. Due to the rich or lean mixture, low charge temperature, and less injection pressure inside the cylinder, leading to high hydrocarbon emissions **(Arcoumanis, et al., 2008).** This type of gas emission occurs because the nanoparticle inclusion with fuel acts as an oxidizing catalyst and accelerates the flame propagation inside the cylinder, which leads to a lower carbon activation temperature and promotes more complete combustion. All these parameters prevent the hydrocarbon emissions from blending nanoparticles with diesel fuel **(Selvan, et al., 2009).**

The nanoparticles additives as observed had a positive effect on UHC emissions. This may be due to the prolonged delay period and higher values of viscosity of nanoparticles, which disturb the fuel atomization and vaporization, and thus, a more extended time was needed to accomplish total ignition or combustion **(Sajith, et al., 2010).**

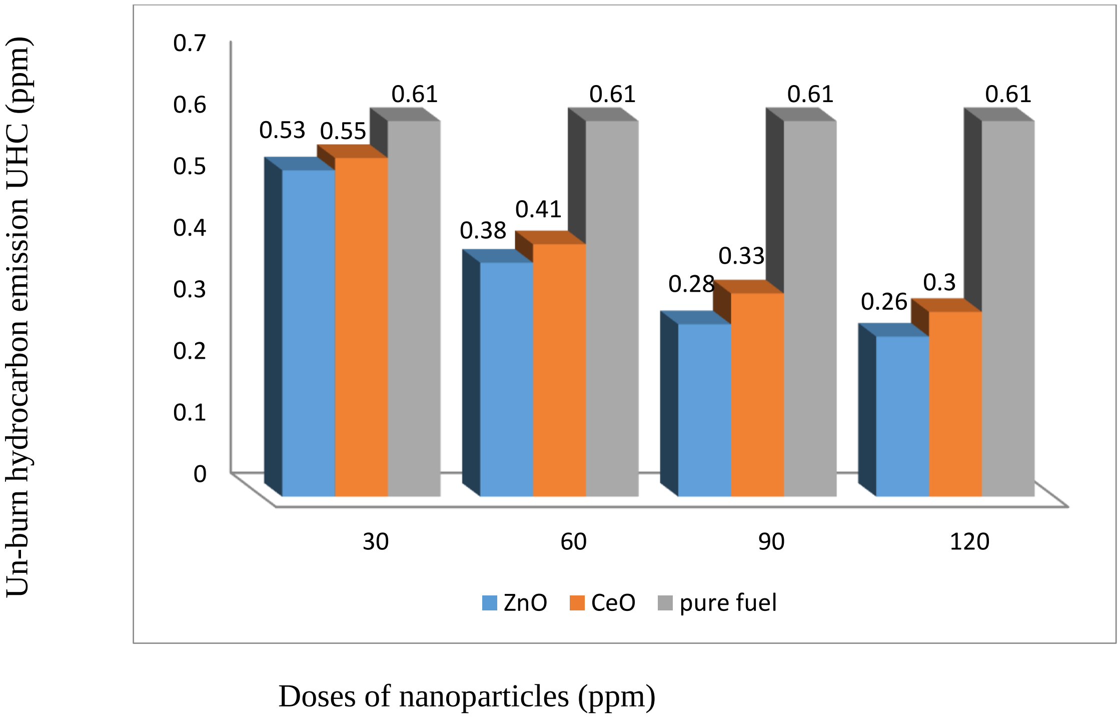

Figure 7. The effect of pure diesel fuel and nanoparticles additives on the un-burn hydrocarbon emission

4. CONCLUSIONS

This research focused on studying the effects of adding two types of nanoparticles (CeO and ZnO) to diesel fuel in variable doses on the engine performance and emission characteristics. According to the results analyzing of research papers, it can be concluded that a range of nanoparticles can be used as additives in diesel fuel. For engine performance, the additive nanoparticles decrease the brake specific fuel consumption for two types of nanoparticles. The best reduction of BSFC was 20% at 30 ppm of CeO and 34.28% at 30 ppm of ZnO. Also, brake thermal efficiency increases with adding nanoparticles. The best improvement in brake thermal efficiency was 60% for ZnO and 58% for CeO. For emission gas parameters, the best reduction of NOx emission from CeO decreased by 58.11% at 120 ppm, while for ZnO it decreased by 63.77% at 120 ppm. For CO, the best value reduction, the emission decreased by 29.26% for ZnO at 120 ppm, while for CeO it decreased by 37.80% at 120 ppm. At 90 ppm, nanoparticles reduce the emissions of CO_2 by 56.41% for ZnO and 61.53% for CeO. UHC emissions decrease when nanoparticles are introduced, where UHC emissions decrease by 57.37% at 120 ppm for ZnO and 50.81% for CeO. Overall, for diesel fuel engines, nanoparticle additives improved engine performance by lowering gas emission values across the board and providing the best combustion and emissions performance.

Nomenclatures and Abbreviations

No.	Parameter	Meaning	Unit
1.	BSFC	Brake Specific Fuel Consumption	kg/kW.hr
2.	CO	Carbon monoxide	ppm
3.	CO_2	Carbon dioxide	ppm
4.	HC	hydrocarbon	ppm
5.	NOx	Nitrogen oxides	ppm
6.	ppm	Part per million	-
7.	rpm	Round per minute	-
8.	LCV	Lower calorific value	KJ/Kg
9.	nm	Nanometre	
10.	UHC	Un-burn hydrocarbon	ppm
11.	η_{bth}	brake thermal efficiency	%

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