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Improvement of Diesel Fuel to Enhance Engine Performance and Emissions Using Zinc Oxide Nanoparticle Additive

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Abstract

The nanoparticles diesel additives played a major role in enhancing diesel performance by improve its efficiency and alter the emissions of CO, NO_x and HC including several hazardous air pollutions. Zinc oxide nanoparticles (ZONP) is used in diesel engines which blended with diesel by using ultra sonicator and a mechanical homogenizer to achieve good dispersing. Five concentration of ZONP are studied in this study. To demonstrate and access the enhanced performance of the nano-diesel blend a comparison of fuel consumption, brake power and engine efficiency with base diesel are made. The addition of ZONP promote combustion by increasing engine performance and reducing the emissions. To evaluate the impact of ZONP on engine performance and environment, several experiments performed on the diesel engine at 1400 rpm which is kept constant throughout the experiment with different range of loads. The results show clearly that by adding the nanoparticles, namely ZONP into the diesel fuel has significant improvement of high the brake thermal efficiency (BTE) and low Brake Specific Fuel Consumption (BSFC) as compared to diesel. Also, the average reduction in CO is 33% for high ZONP concentrations and applied high loads while average increases in CO_2 is 8%, and NO_x is 33% and more for high ZONP concentrations and applied high loads compared to pure diesel. Furthermore, 100% eliminated HC is observed when compared to pure diesel at different loads.

Keyword: diesel engine, engine performance, emissions, nanoparticles additive.

1. Introduction

Energy demand was estimated that the world overall energy consumption will expected to be by more than 30% in the year 2040 [1]. Diesel fuel is one of the primary sources of energy in many engineering applications and industries. Today, there is a great demand of diesel engines in the automobile industry, construction work and marine industries as they are considered more efficient and economical [2]. This is attributed to its high thermal efficiency and low specific fuel consumption [3]. So, it is preferred high thermal properties in nano diesel applications to get better combustion in the engine and to enhance the combustion efficiency. Better combustion shortly means more energy. Otherwise, a poor combustion in the engine undoubtedly causes more carbon monoxide, nitrogen oxide, Sulphur oxide and more smoke to the atmosphere. Also, the combustion quality is directly related to the property of fuels. Furthermore, current focusing on adding additives to fuel due to their advantages of increasing engine performance while reducing the harmful emissions [4-6]. Fuel additives are chemical compounds added in very small amounts to diesel fuel to improve fuel performance and reduce the diesel engine emissions [7, 13]. These fuel additives faces many challenges to provide better combustion characteristics. The most frequently used nanoparticles materials are aluminum oxide (Al2O3), cerium dioxide (CeO_2), copper oxide (CuO), iron oxide (γ -Fe_2O_3), titanium oxide (TiO_2), cobalt oxide and zinc oxide (ZnO) nanoparticles (NPs), carbon nanotubes (CNTs) [4, 6, 8-11]. Metallic nanoparticles are an attractive choice as fuel additives owing to high energy density and reactivity. Also, have a high specific surface area and excess energy of surface atoms, they may exhibit unique physical, chemical,

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thermal and magnetic properties, which may differ substantially from those of bulk materials [12, 14-15]. Exhaust reduction and performance improvement was found to increase with increase in nanoparticles concentration but higher concentration of nanoparticles addition can deteriorate the performance and increase in emissions [16]. The higher concentration of nanoparticles can alter many properties of fuels such as viscosity, density, calorific value, cetane number, and alteration of these properties' effects on both performance and emissions [16-18].

The utilizing of biosynthesis of ZONPs Portulaca oleracea seeds aqueous extract has been reported by Hend et al., and reported that high antioxidant, good antibacterial activity with a higher efficiency of ZnO-60 than ZnO-500 [19]. The present work aimed to investigate the effect of adding ZONP to the diesel fuel on the performance of diesel engine.

2- Material and methods

a. Test Engine

Experiments were conducted to study the effect of nanoparticles addition on combustion phasing of an engine of four cylinder water-cooled direct injection diesel engine with a displacement volume of (553 cm^3). The rated power of the engine is 65 HP at maximum 2000 rpm. It is connected with hydraulic brake dynamometer as shown in Figure (2.1). The engine is fitted with a conventional fuel injection system, which has a three-hole nozzle of 0.2mm diameter separated at 120 degrees, inclined at an angle of 60 degrees to the cylinder axis. The injector opening pressure recommended by the manufacturer is 120 bar. The basic engine specifications are shown in Table (1).

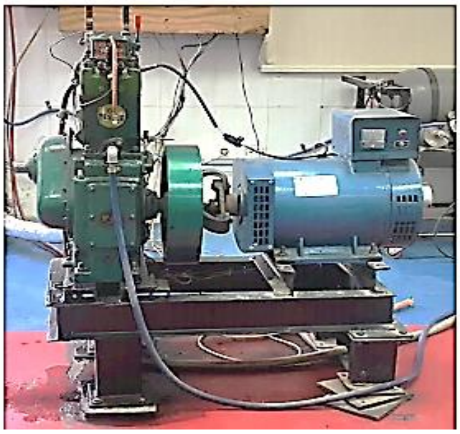

Figure (1): Diesel Engine.

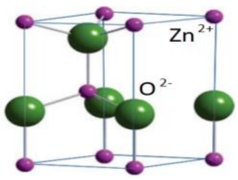

Figure (2): Chemical Structure of Zinc Oxide Nano-Particle

Table 1: Diesel Engine Specifications.

Engine Model	IMR Rakovica R 76 Super
Engine configuration	4 -cylinder
Fuel system	Direct -injection
Rated power	75 HP(55.9 kW)
Torque	272 Nm
Rated speed	2250 rpm
Fuel capacity	8 liter
Cooling system	Water-cooled
Speed range (rpm)	1000-2000

b) *Test Fuel*:

The diesel fuel samples of low Sulphur content used in this experimental investigation have been provided by MIDOR (Middle East Oil Refinery) with the physicochemical properties measured based on the American Society for Testing and Materials (ASTM) are listed in Table 2. Engine test was performed at 3 different speeds (1000, 1200 &1400 rpm) and four different loads (i.e., 5, 10, 15, and 20 lbm). A gas analyzer (Motor branch type 588 A- Italy) was employed to measure CO_2, CO, HC, and NOx. The measurement range of the gas analyzer are presented in Table 3.

Table 2: Diesel Fuel Properties

property	Unit	Method	Result
density at 15 °C	kg/m^3	ASTM D 4052	851.8
Calculated Heat of Combustion (gross)	MJ/kg	ASTM D4846	45.46
Pour Point	°C	ASTM D97	+15
Cetane number	----	ASTM D 613	59.0
Total Sulphur	% wt	ASTM D4294	0.197
Flash Point	°C	ASTM D93	93.0
Ash Content	%wt	ASTM D482	0.0006
Kinematic Viscosity at 40°C	mm^2/s	ASTM D445	4.669

Table 3: Specifications of the Gas Analyzer

Parameter	Range
Hydrocarbon (HC)	0-9999 ppm
CO_2	0-19.9 vol%
CO	0-9.99 vol%
NOx	0-9999 ppm

c) *Nano particle additive*

The Zinc oxide nanoparticles were supplied by NanoTech Egypt for Photo-Electronics (its structure is shown in Figure 2). The characteristics of ZnO nano particle (Table 4) is done by XRD and SEM analysis and are shown in Figures 3 & 4. ZnO aqueous nano-fluid is prepared. A required quantities of each nanoparticle were weighed and blended with the diesel fuel. The blending process were carried out using a probe type ultrasonicate to ensure the deagglomeration of the nanoparticles. This is achieved by the shear forces applied on the nanoparticle agglomerates due to cavitation occurring within the fuel mixture. Thus, five fuel blends were prepared i.e., Zn-20 (dispersion of ZONP in Diesel with a concentration of 20 ppm). Table (5) shows the measured and calculated properties of the pure diesel and the five prepared samples with different ZONP concentrations.

Table 4: Zinc Oxide Nano-Particle Characteristics

Appearance (color)	White
Appearance (form)	Powder
Solubility	Suspended in water
Average size(Z-average)	1315 d-nm
Zeta Potential	7.56 mv

Table 5: Properties Results of the Tested Fuel Blends Samples

Property	Unit	Pure Diesel (D_0)	D_0+ Zn-20	D_0+ Zn-40	D_0+ Zn-60	D_0+ Zn-80	D_0+ Zn-100
Density at 15 °C	kg/m^3	851.8	852.0	852.2	852.4	852.5	852.5
Calculated Heat of combustion (gross)	MJ/Kg	45.46	45.46	45.46	45.46	45.46	45.46
Cetane number	---	59.0	62.1	63.0	63.8	64.9	66.2
Kinematic Viscosity at 40°C	mm^2/s	4.669	4.675	4.677	4.680	4.683	4.688

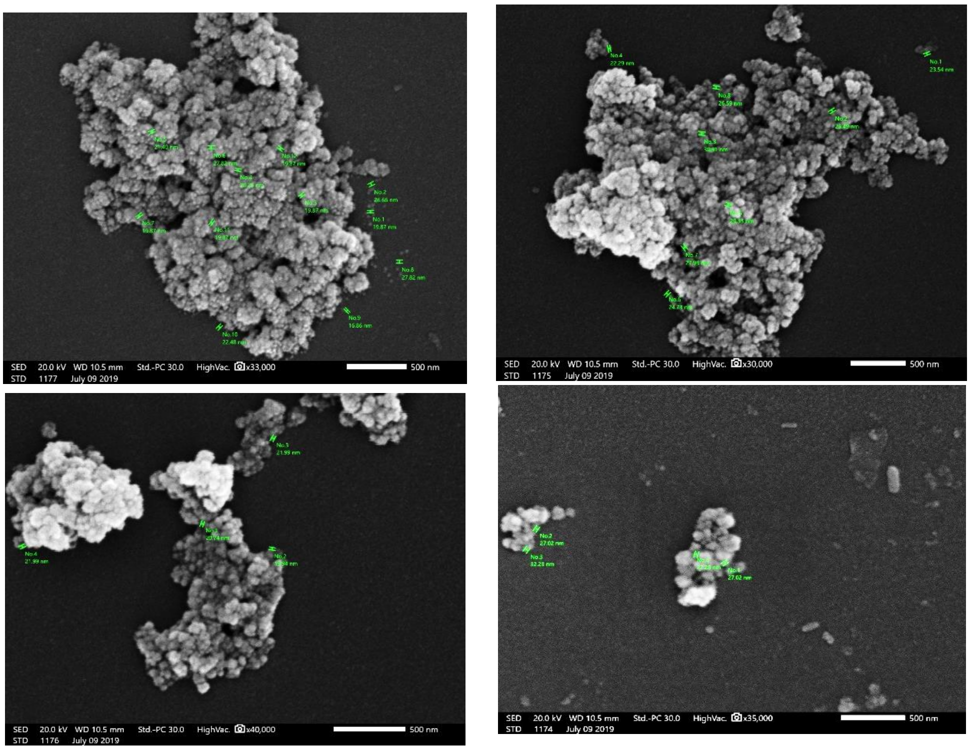

Figure 3: X-Ray Diffraction Pattern of Zinc Oxide Nanoparticle

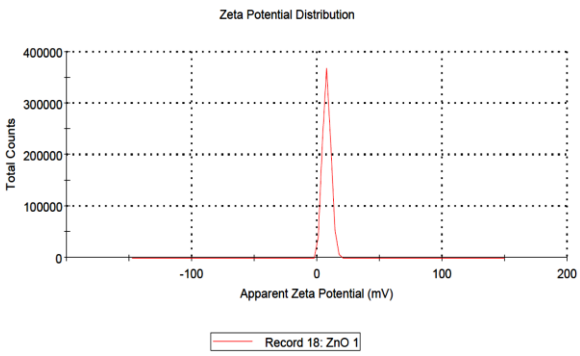

Figure 4. SEM of Zinc Oxide Nanoparticles

3-Results and Discussions

Impact of ZONP as an additive blended with diesel is investigated, in which its effects on diesel physical properties, performance and emission parameters on diesel engine are estimated. The following effects are discussed:-

- Effect of nanoparticles on physical properties:

As shown in Table (5), cetane number was highly improved by increasing ZONP concentration indicating that the combustion efficiency is increased with blending more nanoparticles. However, the density of fuel blends and its kinematic viscosity were not affected.

- *Cetane Number*

The effect of ZONP dose level on the cetane number of the diesel is shown in Figure (5). The cetane number increases by Zinc oxide nanoparticles concentration increases from 59 to 66.2 which indicates good combustion efficiency and reduce the fuel consumption by reducing the delay between moment of injection and start of fuel combustion.

- *Engine Performance:*

1. *Brake power*

Brake power is the measure of the engine's output power, leaving out the power lost in water cooling, exhaust, generator and other loads. The brake power determine the fuel efficiency used in the engine. Figure (6) illustrates five loads run showing the three lines in the graph with respect to RPM. The five fuel samples and the pure diesel have the same launch at a constant brake power followed by an increase in brake power linearly with the load increases and also increases linearly with increases the engine rpm. So, 1400 rpm has been selected to investigate the other engine performance variables and to evaluate the emissions impact.

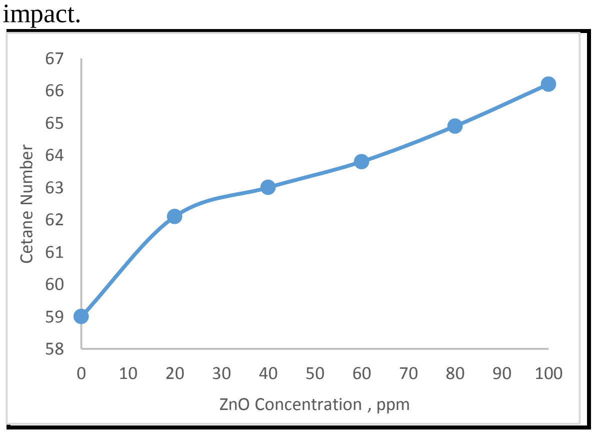

Figure (5): Effect of ZONP Concentration on Cetane Number.

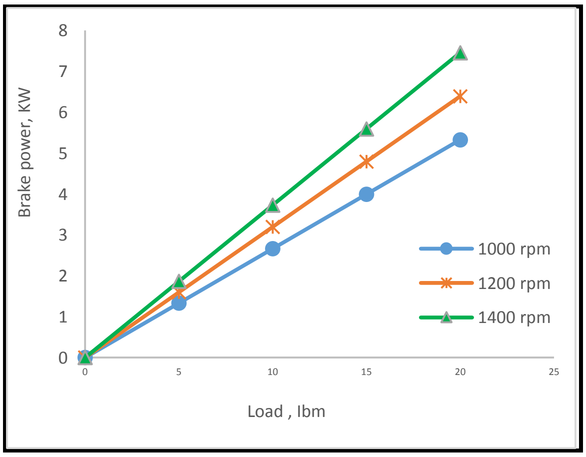

Figure (6): Effect of different loads on brake power at different speeds.

2. Brake Specific Fuel Consumption (BSFC)

Brake Specific Fuel Consumption is the best parameter to compare the performance of an engine when different dispersed nanoparticles are used. The fuel consumption is a measure of the fuel consumed or used per unit distance at a specific time.

$$\textbf{Brake Specific Fuel Consumption (BSFC)} = \textbf{Fuel mass flow rate/Brake power}$$

Figure (7) shows the variation of BSFC with test fuels loads at 1400 engine rpm. With all fuel samples, he figure provides that BSFC has a marked decrease trend from zero load up to 10 Ibm. Furthermore, increase in load from 15 to 20 Ibm showed a slight decrease in BSFC. Other hand, the pure diesel sample shows a smooth relation slight decreasing at an almost constant rate when concentration of ZONP increases. Similarly, the behavior of all samples with different ZONP concentration, probably this can be attributed to fine atomization properties due to particle size of additive. As a result, this factor indicates strongly the highest saving in the fuel consumption and thus saving in the operating cost of fuel.

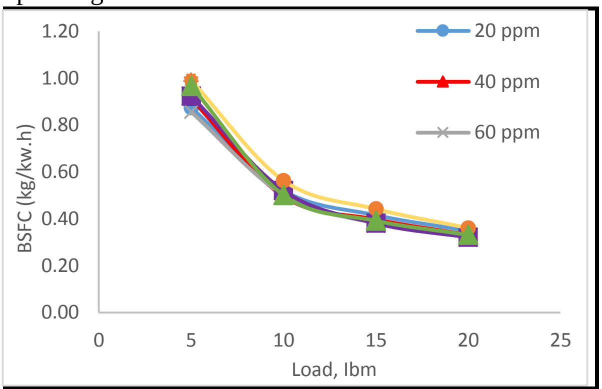

Figure (7): Effect of Different ZONP on BSFC at Different Loads and 1400rpm

From the mechanism point of view, metal-based additives (ZONP) are generally decomposed before the vaporization of fuel and water, releasing active metal atoms which could consequently reduce the formation of unburned carbon deposits on cylinder walls [20]. In turn, this phenomenon may conduct to reduce the friction between the engine parts and finally reducing the BSFC [21, 22].

3- Brake Thermal Efficiency (BTE).

The BTE can be calculated from the following relation [23]:

$$\textbf{Brake thermal Efficiency (BTE)} = \textbf{Brake power / (Fuel mass flow rate} * \textbf{Heating Value)}$$

Figure (8) show the variation of BTE with respect to load of ZONP concentration. The BTE is increased with the increase in load. All at once in BTE, there is a droplets at maximum load and higher ZONP. This explained that the higher loads runs the engine at rich mixture leading to reduce the combustion efficiency.

More specifically, a marked increase in BET on increasing engine load from 5 to 10 lb_m. Yet in further increase in load from 10 to 20 lbm, the increase in BTE is less pronounced compared to the first case. Also, it is clear that for all concentration of ZONP there is marked increasing specially at high engine loads. As a response of adding ZONP to the diesel fuel, the BTE improvement could be attributed by the slightly higher peak cylinder pressure and faster heat release rate [24, 25].

In fact, the positive impact of ZONP on increasing BTE could be attributed to lower friction between the engine parts according to the relation between BTE and BSFC. During the combustion process high temperature, the chemical reaction between ZONP and carbons could prevented effectively the formation of carbon deposits on the cylinder wall [26]. The present study findings agree with previous reports on metal-based additives application [27].

For all fuels testes, the BSFC reduced while the BTE improved with the increase in engine load. At a high engine load, this may explained due to the fuel combustion quality improvement and may also to the enhancement of combustion processes because of nanoparticles effect as a catalytic [28].

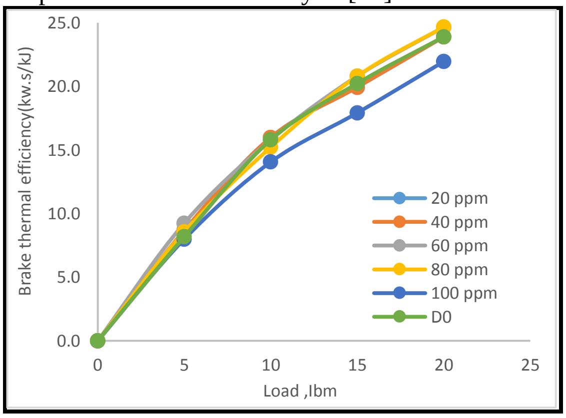

Figure (8): Effect of Different ZONP on BTE at Different Loads and 1400 rpm

- Emission Characteristics

a- Variation of CO Emission

Carbon monoxide forms in internal combustion engine as a consequence of incomplete combustion due to insufficient air or cold engine temperature. The lack of oxygen and/or low temperature in the cylinder results in a failure in the oxidation process of CO to CO2. The variation of CO emissions with engine loads at 1400 rpm engine speed and different dosage of ZONP as additive is shown in Figure (9). From these results it can be seen that at 1400 rpm, by increasing compared to diesel at different loads except for ZONP (20 and 40 ppm) due to higher combustion temperatures which enhances the oxidation of more CO to CO_2 [29].while by increasing nano particles concentration to diesel from 60 ppm to 100 ppm, there is no change in CO emissions at different loads.

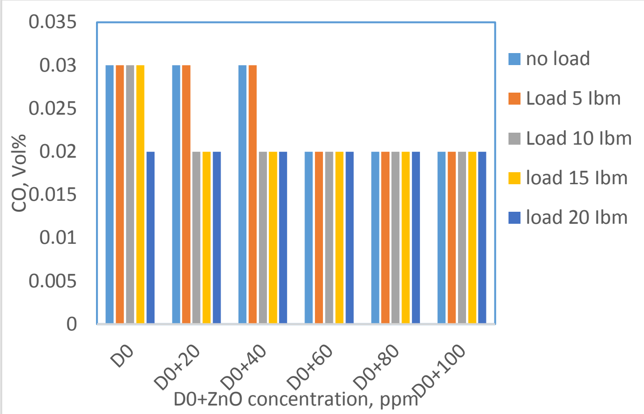

Figure (9): Variation of CO Emission at 1400 Rpm for Different ZONP Concentrations at Different Loads.

b- Variation of CO2 Emission

Carbon dioxide is one of the main combustion products and its existence is an evidence of complete combustion. The CO_2 emissions for pure diesel and diesel with different concentrations of ZONP at different engine loads is shown in Figure (10). The results showed that by increasing the engine loads and zinc oxide nano particles concentrations, the CO_2 emissions slightly increased, this can be explained to high combustion efficiency of fuel [29-31].

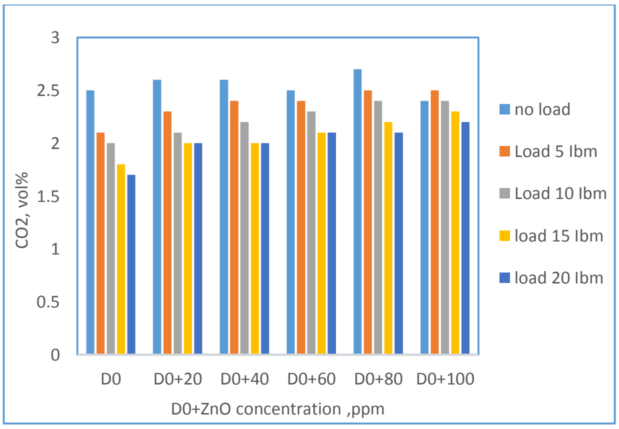

Figure (10): Variation of CO_2 Emission at 1400 Rpm for Different ZONP Concentrations at Different Loads.

c- Variation of HC Emission

Mostly, Hydrocarbon emissions are a product of incomplete combustion of fuel. There is no hydrocarbon (HC) emissions with different engine loads at different speed for diesel and ZONP concentrations as shown in Table (6). This can be attributed to the catalytic action of ZONP which improves the combustion process leading to oxidation of unburnt HC that resulting in eliminate HC emissions. Furthermore, because of the excellent air– fuel mixing.

Table (6): Variation of HC emissions

LOAD	D_0	D_0+ Zn-20	D0+ Zn-40	D0+ Zn-60	D0+ Zn-80	D0+ Zn-100
No load	0.14	0	0	0	0	0
Load 5 lb_m	0.14	0	0	0	0	0
Load 10 lb_m	0.14	0	0	0	0	0
load 15 lb_m	0.14	0	0	0	0	0
load 20 lb_m	0.14	0	0	0	0	0

d. Variation of NOX Emission

Nitrogen oxides, NOx, are produced by oxidation of atmospheric nitrogen in combustion .The variation of NOx emissions with engine loads at 1400 rpm speed and ZONP concentrations is shown in Figure (11). The additional oxygen content in the ZONP increases the cylinder combustion temperature which lead to increases in NOx emissions [30] .Also increasing the engine load leads to an increase in temperature in combustion chamber resulting in increased in NOx emissions. [28, 31].

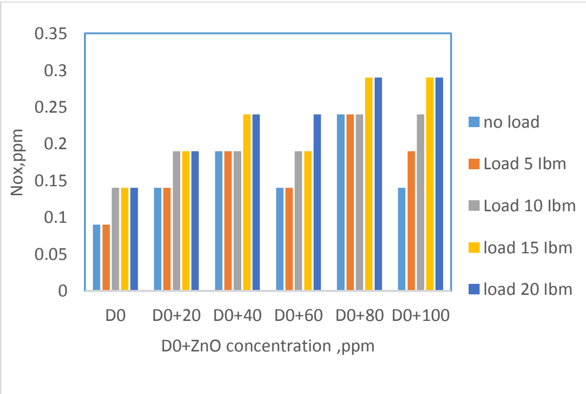

Figure (11): Variation of NO_x Emission at 1400 Rpm for Different ZONP Concentrations at Different Loads.

4- Conclusion

The performance, and emission characteristics of a four-cylinder water-cooled direct injection diesel engine with nano-additive enhanced diesel was investigated to understand the effects of zinc oxide nanoparticles as a fuel additive in diesel. Based on the experimental results, the following conclusions are:

1. The addition of zinc oxide nanoparticles in a diesel fuel increases the cetane number which indicates for good combustion efficiency and reduce the fuel consumption.
2. As load increases the brake power increases linearly with increases the engine rpm.
3. Addition of Zinc oxide nanoparticles from 20 to 80 ppm led to slight increase in BTE and reduction in BSFC in low-to-medium loads compared to pure diesel.
4. CO emissions were reduced by increasing Zinc oxide nanoparticles up to 40 ppm after that no change occurs.
5. Addition of Zinc oxide nanoparticles increases CO2 and NOx emissions.
6. HC emissions are completely eliminated in presence of Zinc oxide nanoparticles.

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