Experimental Investigation of Pollutants Emissions for a Diesel Engine Fuelled with Nano Fuels.

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Abstract

This experimental work aims to examine the effect of nanoparticles added to diesel fuel on engine emission characteristic. Nano fuels are prepared by adding Al_2O_3 or TiO_2, both with particle size less 45nm to diesel fuel. Four doses for each type namely (25, 50, 100 and 150) ppm are prepared. These nanoparticles are blended with diesel fuel in varying volume fraction by the means of an electric mixer and an ultrasonicator (JTS-1018). Their stability characteristics were analyzed under static conditions. The Nano fuels are (DF+Al_2O_3) and (DF+TiO_2). The study shows that the addition of nanoparticles to diesel fuel improves in physical properties such as cetane number where it increases from 51.6 to 54.3 for Al_2O_3 at 150ppm. Also Comparisons of fuel properties without and with nanoparticles additives (Al_2O_3 and TiO_2) are presented. The influence of nanoparticles addition is very clear on the emission characteristics. The results show that the Al_2O_3 and TiO_2 reduce the CO emission by 34% and 25% respectively at 75% load and 25ppm. The NO_x emission is increased with Al_2O_3 by 4.12% at 25ppm and full load, but with the TiO_2 is decreased by 10.56% at same operating conditions. The reduction of smoke opacity with Al_2O_3 and TiO_2 is 28% and 25% respectively.

Key words: - Nano fuel, Nanoparticle, Exhaust emission, Diesel engine.

Nomenclature		**Unit**	**Greek symbols**		**Unit**
C_p	Specific heat	J/kg.ºC	μ	Dynamic viscosity	kg/m.sec
k	Thermal conductivity	W/m ºC	ρ	Density	kg/m^3
m	Mass	kg	φ	Solid volume fraction of nanoparticles	%
			Subscripts		
			f	fuel	-
			nf	Nanofuel	-
			p	Nanoparticle	-

1. Introduction:

Urban air pollution due to vehicular emission is a matter of concern because of exposure of large number of people to it. Vehicular emission is responsible for higher level of air pollutants like NOx, CO and other organic and inorganic pollutants including metal traces and their adverse effects on human and environmental **[1]**.

[2] Investigated experimentally the effect of adding magnetic nanoparticle (10nm) with dose of 0.4 and 0.8 fero by volume to the diesel fuel. The tested engine was 4strokes, 4cylinders with 43 kW, water-cooled and constant speed (4800 rpm). The results showed that these additions enhanced D+4F and D+8F decreased NO_x emission at all loads. Adding 0.4% Ferro fluid to diesel fuel reduced NO_x emission by 9 to 15 ppm while adding 0.8% Ferro fluid to diesel fuel reduced NO_x emission by 14 to 24 ppm. The carbon monoxide (CO) emission increased with D+4F by 10 to 17 ppm and with D+8F increased by 21 to 42 ppm. [3] analyzed experimentally the effect of nanoparticles on the combustion, performance and emission characteristic of single – cylinder, air cooled and directed injection (DI). They used MnO (200 mg/L) and CuO (200 mg/L) as an additive metal. The highest UHC was observed at lower load but with full load 1% decline was observed. The manganese additive showed a decrease in CO and NO_x emission by 37 % 4%. [4] Studied effect of nanoparticles additive on the palm oil biodiesel. They used nanoparticles (TiO_2) with dosing 1 % and 5% palm oil and 95 % pure diesel fuel. The emission of CO, UHC, NO_x and soot were all decreased. [5] Examined experimentally the effect of addition of energetic nanoparticles such as aluminum, iron and boron to diesel fuel in a single cylinder of compression ignition engine. Pollutants emission like carbon monoxide concentration was reduced by 25-40% when additives are added to neat diesel fuel. UHC concentration was also reduced by 8% and 4% for engine fueled with energetic nonfuel such as aluminum and iron when compared with engine fueled with neat diesel fuel.[6] examined experimentally the effect of mixing of nanoparticle zine oxide (ZnO) with biodiesel fuel (Pomolion stearin wax) on the combustion characteristics and emission. Their study was carried out on a single cylinder, air cooled, and stationary DI engine at constant speed 1500 rpm. The UHC(unburnt hydrocarbons), CO and smoke emission were reduced. Not much difference with value of NOx was observed [7] investigated experimentally the effect of addition of nanoparticles to the diesel fuel on the emission of NO_x. Four cylinder, four-stroke, naturally aspirated and water-cooled direct injection compression ignition engine was used in their study. Nine nanoparticles such as MgO, Al_2O_3, TiO_2, ZnO, SiO_2, Fe_2O_3, NiO, $NiFe_2O_4$ and $ZnO0.5NiO0.5Fe_2O_2$ were used. They found that addition of all nanoparticles expect $A1_20_3$ led to a reduction in the NO_x emission. The maximum reduction was found at 100 ppm dosing of MgO. [8] investigated experimentally the effect of Al_2O_3 as additive to the biodiesel. The test was performed on a single cylinder, direct injection (DI) and water cooled engine. They used 25 % of was zizipus jujube methyl ester blended fuel (ZJME25). Along with ZJME25 aluminum oxide nanoparticles were added as additive in mass fraction of 25 ppm (AONP25) and 50 ppm (AONP50). UHC(unburnt hydrocarbons), CO and smoke opacity decreased by 0.138 g/kW.hr, 3.951 g/kW.hr and 15-20% respectively. NO_x increased by 3.456 g/kW.hr, 3.729 g/kW.hr for 25ppm(AONP25), 50ppm(AONP50) respectively. [9] investigated experimentally the effect of alumina oxide Al_2O_3 nano additive on performance and emission in methyl ester of neem oil fueled direct injection diesel engine. The alumina oxide nanoparticles are mixed with biodiesel in various proportions from 100 ppm, 200 ppm and 300 ppm. The size of nanoparticles was (1 to

110 nm). The performance and emission were studied in a single cylinder, 4 stroke, stationary, constant speed 1500 rpm, 3.5 kw rated power, water – cooled diesel engine. The addition of nanoparticles reduced NO_x as 3.12%, 7.15% and 4.97% for (MENO + 100 ppm Al_2O_3), (MENO + 200 ppm Al_2O_3) and (MENO + 300 ppm Al_2O_3) respectively. [10] presented an experimental study for improving the performance of single cylinder, four stroke, water cooled compression ignition diesel engine by the addition of nanoparticles such as cobalt oxide (Co_3O_4) and titanium oxide (TiO_2). There was a reduction in carbon monoxide (CO) emission for nanoparticles blended biodiesel by adding cobalt oxide (Co_3O_4) there was 30% reduction in CO, while titanium oxide (TiO_2) blended biodiesel showed 25% reduction in CO. There was a reduction in Unburned Hydrocarbons (UHC) with the cobalt oxide (Co_3O_4) and the titanium oxide (TiO_2) by 80%, 70% respectively. [11] Studied experimentally the influence of addition of titanium oxide (TiO_2) nanoparticle to diesel fuel in a compression ignition engine. The experiments were conducted at constant speed of 1500 rpm and for compression ratio of 17.5. The size of nanoparticles was 10 to 20nm and the dosing level was 80mg/L. Emission concentration such as unburnt hydrocarbon (UHC) and Carbon monoxide (CO) was decreased by 18% and 25% respectively. [17] examined experimentally the effect of addition of nanoparticles A_2O_3 and TiO_2 to diesel fuel in a single cylinder of compression ignition engine. Pollutants emission like carbon monoxide concentration was reduced by 40% and 46% for DF+Al_2O_3 and DF+TiO_2 respectively, while the CO_2 is increased by 6.7% and 8% for DF+Al_2O_3 and DF+TiO_2 respectively at 25ppm and 75% load. The nitrogen oxide NO_x is increased with DF+Al_2O_3 from 1013ppm to 1055 ppm, while it is decreased with DF+TiO_2 from 1013ppm to 906ppm at full load and 25ppm.The smoke opacity is decreased by 28% and 25% for DF+TiO_2 and DF+Al_2O_3 respectively. The UHC is increased with DF+Al_2O_3 and it is decreased with DF+TiO_2 about 8% at full load and 25ppm

2. Experimental Setup

Experiments were conducted to study the effect of nanoparticles addition on combustion emission on a single cylinder 4-stroke water-cooled direct injection diesel engine with a displacement volume of (553 cm^3), variable compression ratio, developing 3.7 kW at 1500 rpm. 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 complete rig set up is shown in plate (1) and schematically in fig (1). The data acquisition and engine control system is shown in plate (2). The system records the pressure via crank angle diagram (p, θ), engine speed (rpm) and temperature of exhaust gases.

3. Fuel and Nano fuel Preparation

The fuel used in this study is gas oil (diesel) $C_{12.3}H_{22.2,}$ with a density of 844.3 kg/m^3 and a dynamic viscosity of $2.778*10^{-3}$ (kg/m.s). Two types of nanoparticles are chosen, namely Al_2O_3 and TiO_2 with particle size less than 45 nm to be blended with the 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 equation (1) below

[16].

$$\phi = \frac{\frac{m_p}{\rho_p}}{\frac{m_p}{\rho_p} + \frac{m_f}{\rho_f}} \quad (1)$$

The physical properties of the nanoparticles and pure diesel fuel used to prepare to Nano fuel are shown in table (1).

Table (1) shows the physical properties of nanoparticles and diesel fuel [15]

Substance	Density (kg/m^3)	Dynamic viscosity*10^3 (kg/m.s)	Specific heat (J/kg.K)	Thermal conductivity(W/m.°C)
Al_2O_3	3970	-------	765	40
TiO_2	4230	-------	710	9
Diesel fuel	844.3	2.778	-------	-------

Table (2) shows the mass of nanoparticles required for each dose for both types as calculated by equation (1).

Table (2) Mass of nano-particles (for five liters of fuel)

Volume ratio (ppm)	ϕ%	Mass of particles (m_p) (g) (Al_2O_3)	Mass of particles (m_p) (g) (TiO_2)
25	0.0025	0.4963	0.529
50	0.005	0.993	1.058
100	0.01	1.986	2.116
150	0.015	2.979	3.174

The measured quantity of nanoparticles is added to five litter (5 L) of diesel fuel and mixed continuously for one hour by the mixer, shown in plate (3), to ensure the spreading of nanoparticles within the diesel fuel to prevent aggregation of particles quickly. An ultrasonic cleaner type (JTS-1018), shown in plate (4), is used to complete the mixing process. The mixing process continues for another six hours.

4. Measurement System of Engine Exhaust Emission

4.1. Exhaust Gas Analyzer

The exhaust Gas analyzer type 953254 has been used for measuring CO, UHC, and CO_2 in engine exhaust by the principle of non-dividing infrared absorption and for measuring NO_X and O_2 by the principle of electrochemical cell. Plates **(5)** shows the images of the gas analyzer and its connections. The technical specifications of the gas analyzer are given in table **(4)**

4.2. Diesel Smoke Meter

Smoke meter BOSCH model MED 001 is used to measure, display and print out smoke concentration in the exhaust gases. Plate **(6)** shows the image of the BOSCH smoke meter with its remote control while table (5) shows its specifications **[12]**.

5. Results and discussions

The exhaust emission of diesel engine becomes increasingly harmful and worldwide problem and solutions must be sought. Nanoparticles addition to diesel fuel is one approach of reducing this emissions. The following sub-sections present the result of the present study.

5.1. Carbon Monoxide (CO)

The CO emission decreases generally with the increase of engine load until rated load and increases at full load due to better combustion present and higher cylinder temperature. Carbon monoxide (CO) emission of the diesel fuel, which is formed due to incomplete combustion of fuel air-mixture in the combustion chamber is found to decrease with the addition of both (Al_2O_3 and TiO_2)nanoparticle. Figs 2 and 3 exhibit the carbon monoxide (CO) emissions versus engine load for different doses. In general the addition of nanoparticles reduces CO emission. It is very clear that 25ppm is the best dose for both types. The Al_2O_3 and TiO_2 reduce the CO emission by 34% and 25% at 75% load and 25ppm respectively. This results are in agreement with results of **[14].**

5.2. Carbon dioxide (CO_2)

It is noticed that carbon dioxide emissions increase as the load increase and reaches maximum of 75% load and then decreases at full load due to increase of mixture richness. The maximum CO_2 emission is found in pure diesel fuel and increases as the nanoparticles increase in both type due to supply of oxygen and good mixing. Increasing carbon dioxide is a good indication of better combustion process. Figs (4 and 5) show the variation of $CO_2$with engine load. Their higher magnitude indicates the complete combustion in the engine cylinder on par with the reduction of other emissions. In oxygen and rich mixture. This results are in agreement with **[13].**

5.3. Variation of Nitrogen Oxides (NO_x) Emissions

Figs. (6 and 7) show the effect of adding nanoparticles to diesel fuel on NOx emission. NO_x emission is mainly depended on temperature and oxygen availability. The nanoparticles possess high surface areas, which increase their chemical reactivity that in turn reduces the ignition delay. It is found that the addition of 25ppm Al_2O_3 gives the maximum increase in NO_x while the addition of 25ppm TiO_2 produces the maximum reduction in NO_x. This contradicting effect of both types may be attributed to their effect on fuel delay period and heat release in both premixed and diffusion stages of combustion.

5.4. Variation of Smoke Opacity

The variation of smoke opacity with engine load and nanoparticles dose is shown in figs 8 and 9. The smoke opacity decreases with both (DF+Al_2O_3) and (DF+TiO_2) blends when compared with neat diesel. The least smoke is observed as 25 ppm for both of them. The reduction of smoke opacity with Al_2O_3 and TiO_2 is 28% and 25% respectively compared with pure diesel. This is due to better mixing and combustion processes caused by the presence of nano-particles.

5.5. Variation of Unburnt Hydrocarbon (UHC) Emissions

Fig 10 shows that the addition of Al_2O_3 nano-particles to diesel fuel reducesUHC at no load conditions; while increasesUHC at high loads. This is due to higher evaporation of fuel caused by the nano-particles, which have high thermal conductivity. On the other hand, fig11 shows that TiO_2 nanoparticles reduce UHC at all no load and load conditions. The maximum effect occurs at 25ppm. This may be due to lower thermal conductivity of TiO_2 nano-particles compared to Al_2O_3 nanoparticles.

6. Conclusions

1. The dose of 25 ppm for both types gives best reduction in CO emissions.
2. Carbon dioxide emission increases as the load increases, reaches maximum at 75% load, and then decreases at full load. It also increases with nano-particles dose.
3. The NO_x emission increases with Al_2O_3 by 4.15%especially at 25ppm at full load, but with the $TiO_{2,}$ it decreases by 10.56% at full load and 25 ppm.
4. The minimum smoke is observed at 25 ppm for both types. The reduction of smoke opacity with Al_2O_3 and TiO_2 is 28% and 25% respectively.
5. UHC emissions for ($DF+Al_2O_3$) increases by 5.6% due to high viscosity and the faster evaporation. However, with TiO_2 decreases especially with 25ppm around 8% compared to base engine.

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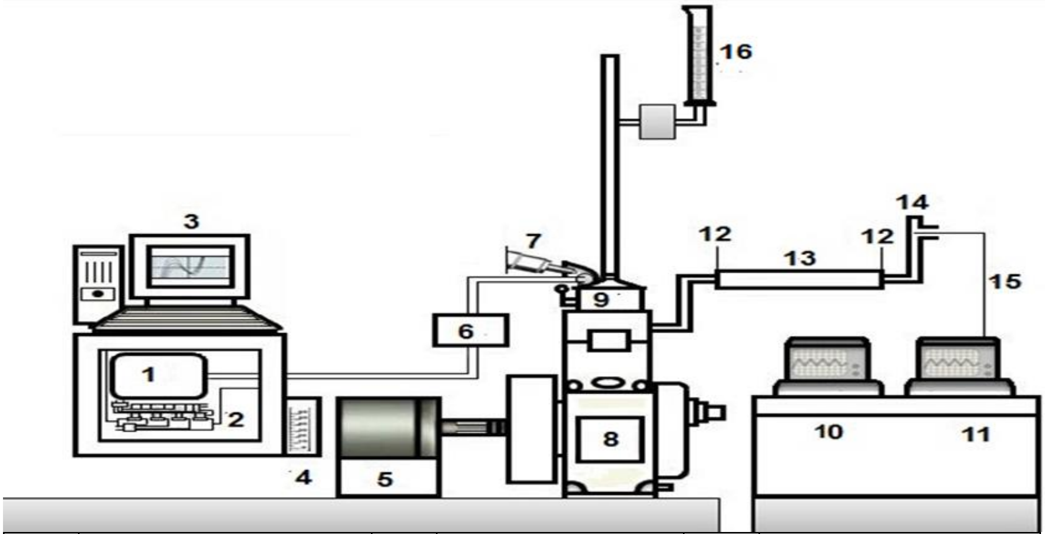
Plate (1) Front View of the Experimental Set Up.



1	Air surge tank	7	Fuel injector	13	Calorimeter
2	Data Logger	8	Engine block	14	Silencer tip
3	PC	9	Cylinder head	15	Exhaust gas probe
4	Water manometer	10	Gas analyzer	16	Fuel tank
5	Eddy current	11	Smoke meter		
6	Intake air	12	PT-100 sensor		

Fig (1) Schematic Diagram of Experimental Set Up.

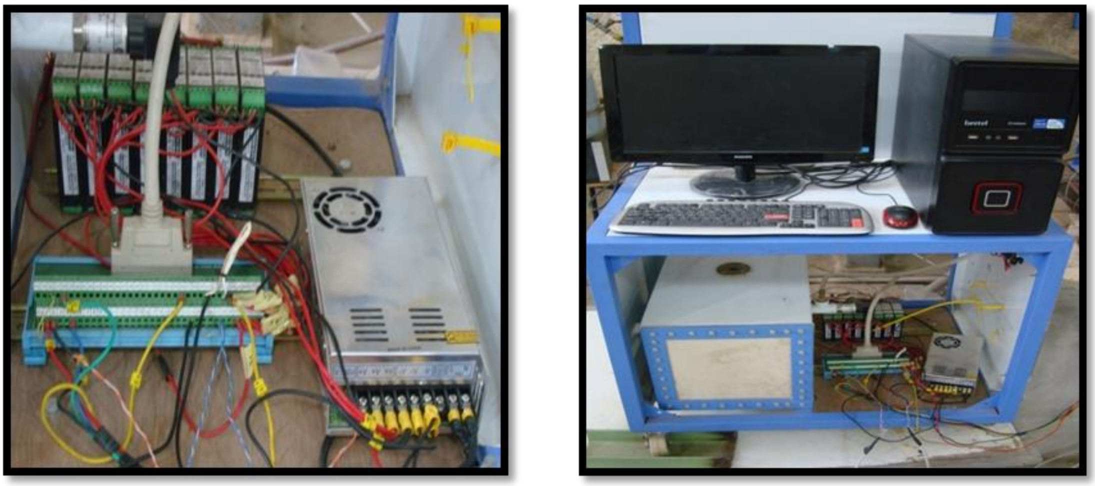


Plate (2) Data Acquisition System

Plate (3) Photograph of Mixer

Plate (4): Photograph of Ultrasonic Cleaner

Model	JTS-1018
Tanks working dimension (mm)	L_1= 406 , W_1=305, H_1=460
Overall dimension (mm)	L_1= 586 , W_1=485, H_1=680
Ultrasonic frequency	40 kHz
Ultrasonic power	720 Watt (variable)
Digital timer control	1-30 min
Capacity	54 liter
Temperature control range (°C)	< 90 °C
Ultrasonic power output	800 W

Table (1-4) Specifications of Ultrasonic Cleaner Bath

Plate (5): The Images of the Gas Analyzer and Its Connection

Table (4): The Technical Specifications of the Gas Analyzer.

ID	Measurement parameters	Range	Resolution
1	HC	0 to10000 ppm	1 ppm
2	CO	0% to 10%	0.01%
3	CO_2	0% to 20%	0.01%
4	O_2	0% to 25%	0.01%
5	NO	0 to 5000 ppm	1 ppm
6	Operating temperature	+ 5°C to + 40°C	
7	Atmospheric pressure	70 kPa to 106 kPa	
8	AC Power supply	AC 220V±15%	
9	Frequency	50Hz± 1Hz	
10	Warm up time	10 minutes	
11	Net Weight	7 kg	

Plate (6): The BOSCH Smoke Meter with the Remote Control

Table (5): The Technical Specifications of the Smoke Meter

ID	Measurement parameters	Range	Resolution
1	Opacity	0-99.9%	0.10%
2	K-value	0-9.99 m^{-1}	0.01 m^{-1}
3	Linearity	$\pm$ 0.1 m^{-1}	-
4	Repeatability	$\pm$ 0.1 m^{-1}	-
5	Response time-physical	< 0.4 sec	-
6	Response time-Electrical	< 1 milli sec	-
7	Warm up time	< 7 min	-
8	Operating Temperature	+5 °C to + 50 °C	
9	AC Power supply	100-265V AC Single phase	

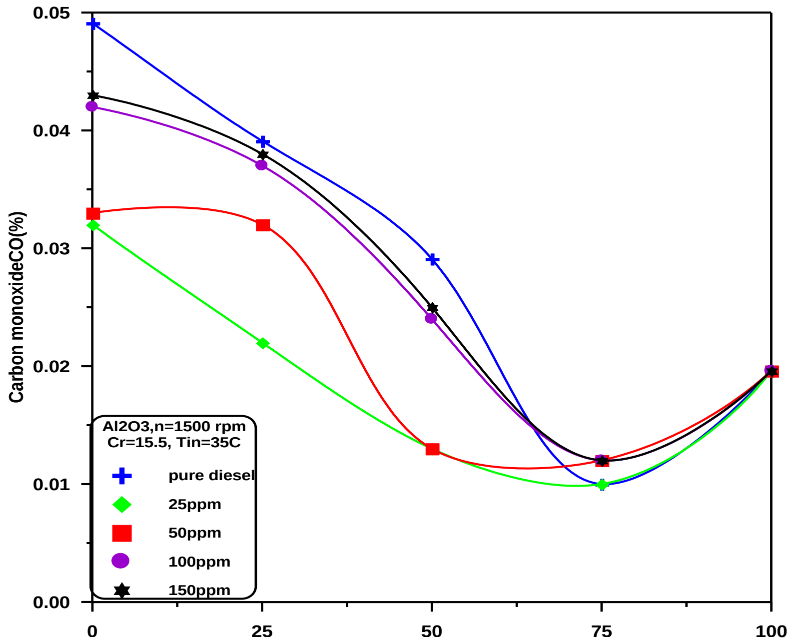


Figure 2 Variation of Carbon Monoxide with Loads

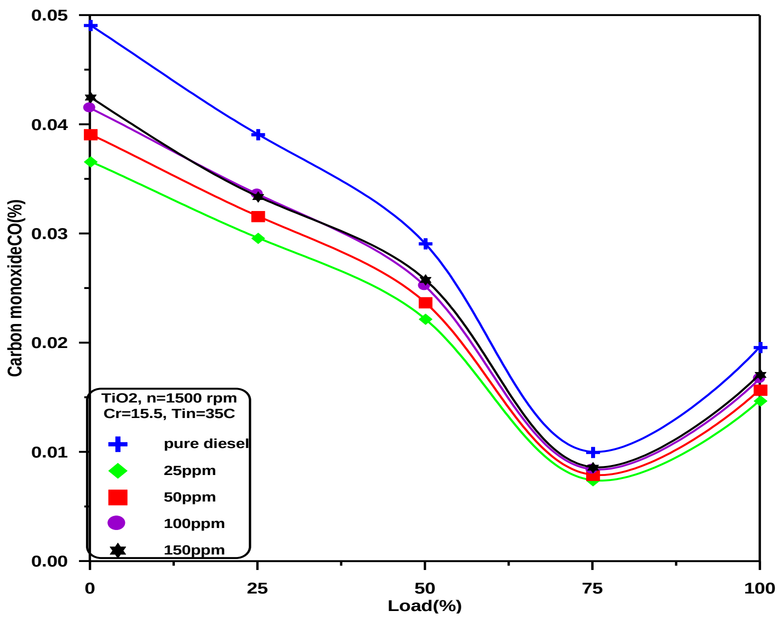


Figure 3 Variation of Carbon Monoxide with Loads

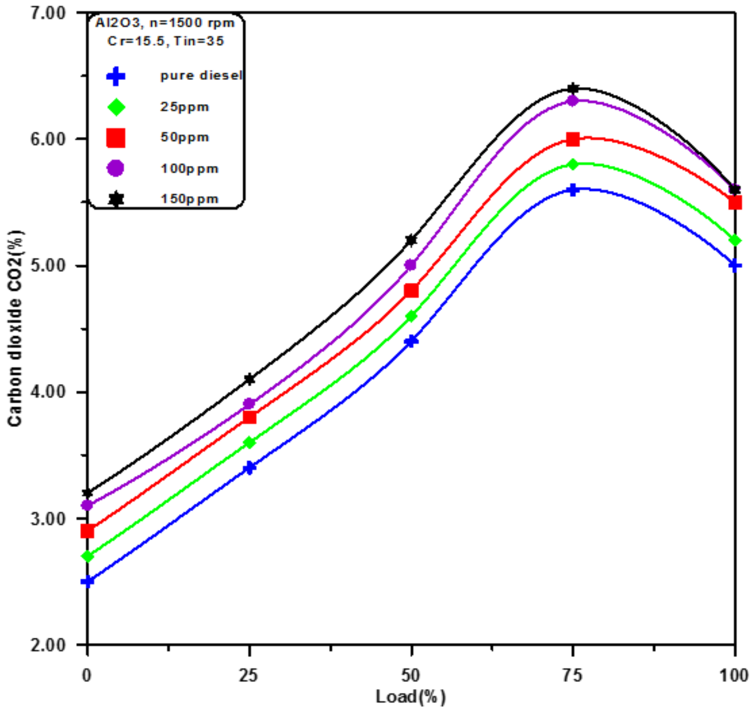


Figure 4 Variation of Carbon Dioxide with Load

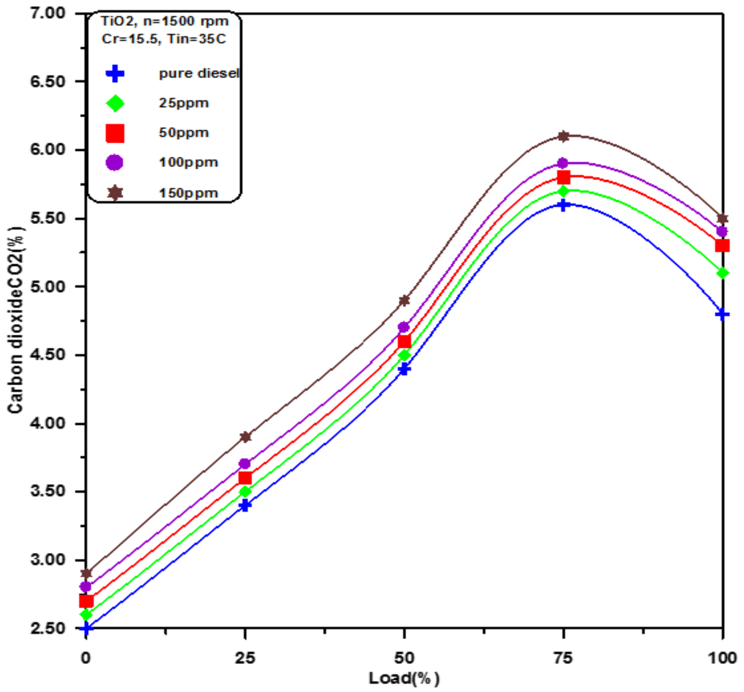


Figure 5 Variation of Carbon Dioxide with Load.

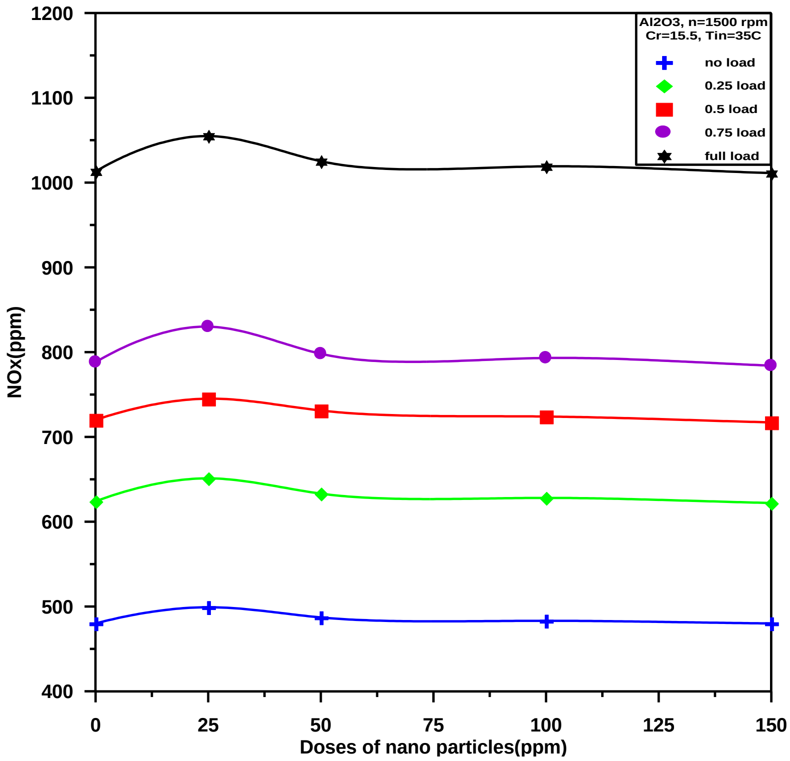


Fig 6: Variation of Nitrogen Oxide Emissions with Nanoparticles Dose

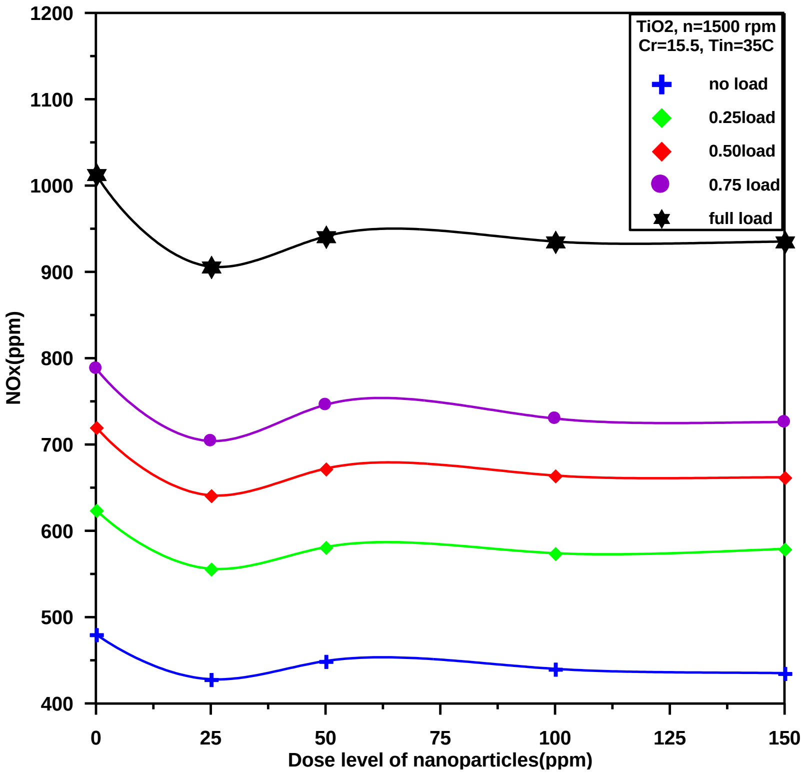


Fig 7: Variation of Nitrogen Oxide Emissions with Nanoparticles Dose

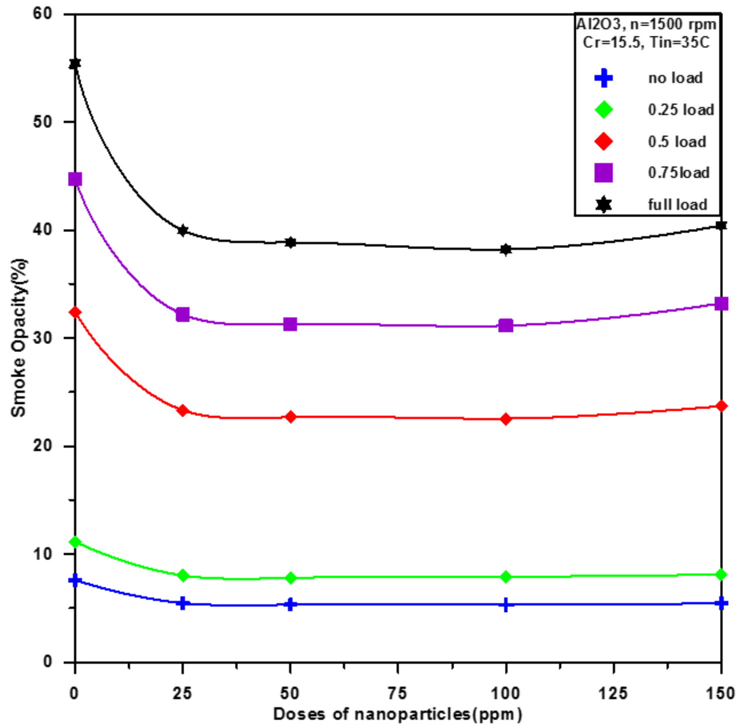


Fig 8: Variation of Smoke Opacity Emissions with Nanoparticles Dose.

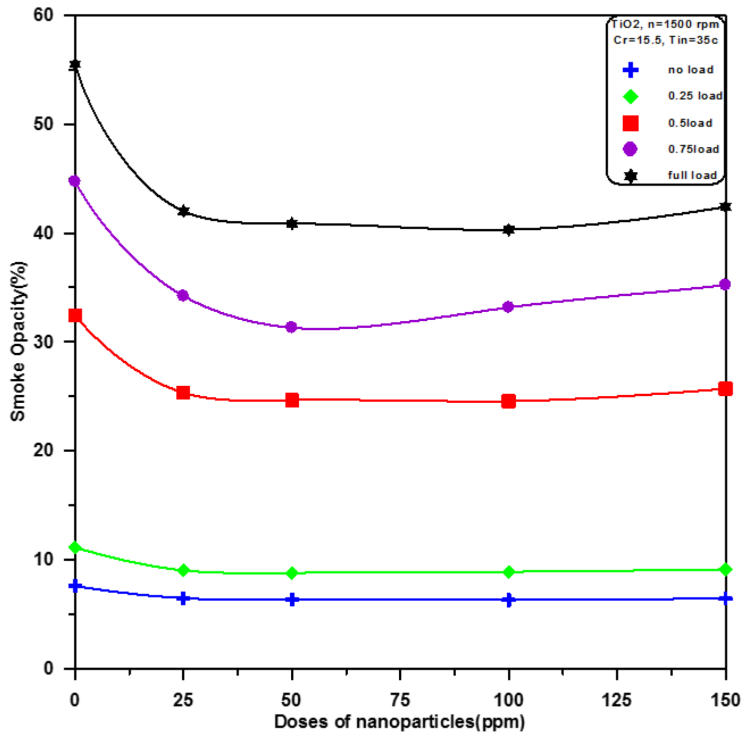


Fig 9: Variation of Smoke Opacity Emissions with Nanoparticles Dose.

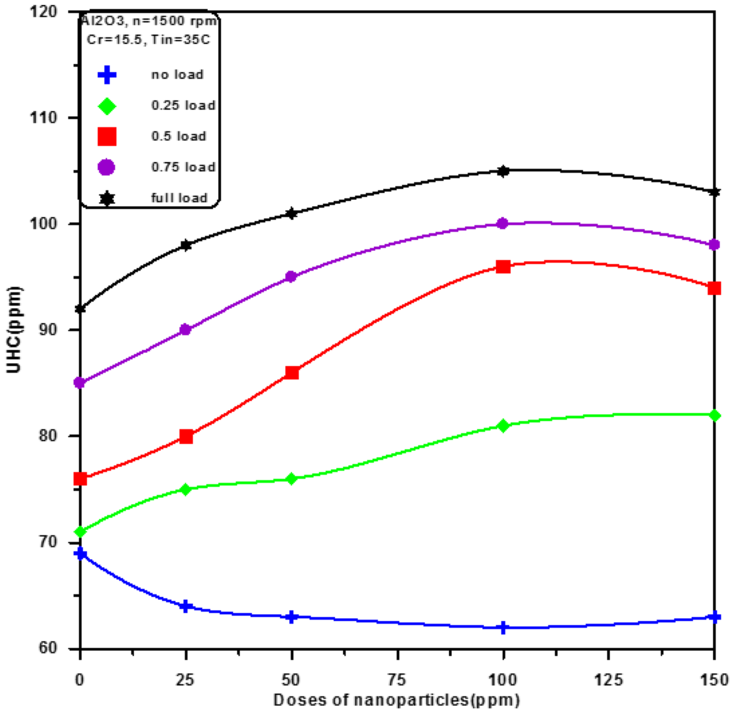


Fig 10: Variation of Unburnt Hydrocarbon Emissions with Respect To Nanoparticles dose level.

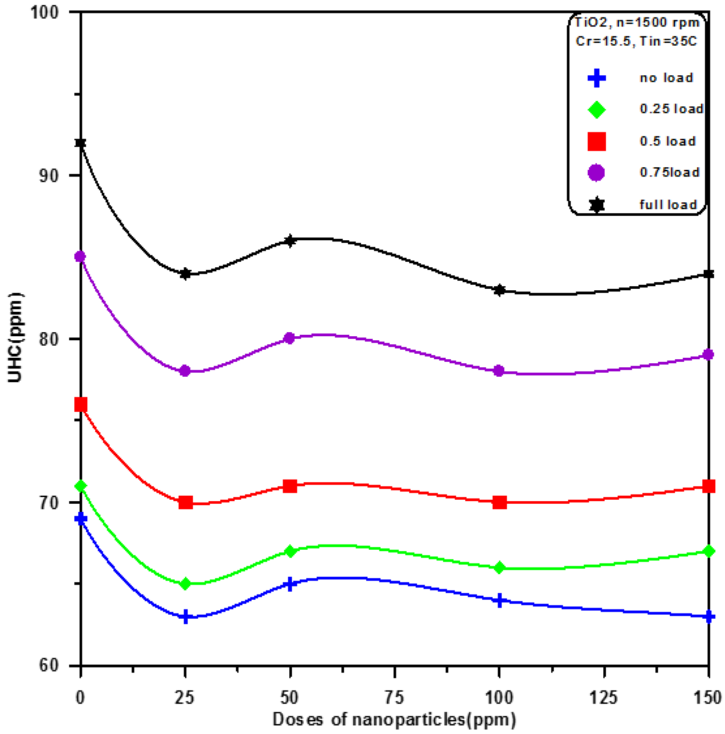


Fig 11: Variation of Unburnt Hydrocarbon Emissions with Respect To Nanoparticles Dose Level.

دراسه عمليه لانبعاث المملوثات من محرك الديزل يعمل بوقود الديزل النانوي

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الخلاصه

تم في هذا البحث دراسه عمليه حول تاثير اضافة حبيبات متناهيه في الصغر (حبيبات النانو) الى وقود الديزل وتاثيرها على خواصه وعلى الانبعاثات.تم استخدام نوعين من حبيبات النانو وهما اوكسيد الالمنيوم واوكسيدالتيتانيوم وباربعة تراكيزوبنسب حجميه وهي(25، 50، 100، 150) جزء واحد لكل مليون جزء وبقطر اقل من 50 نانومترعند احمال ،سرع ونسب انضغاط مختلفه وبالنسبه للانبعاثات فقد لوحظ انها انخفضت بنسب متفاوته. اول اوكسيد الكاربون كان للديزل النقي (0.0167) وانخفضت بنسبة 40% و% 46(ديزل+ اوكسيد الالمنيوم) و(ديزل +اوكسيد االتيتانيوم) على االتوالي واما بالنسبه لثاني اوكسيد الكاربون كان هناك زيادة بنسبة 6.7% و8% (ديزل +اوكسيد التيتانيوم) و(ديزل+اوكسيد الالمنيوم) على التوالي وعند تركيز 25 وحمل 75%. اوكسيد النتروجين فانه زاد في حالة (ديزل+اوكسيد الالمنيوم) من1013 الى 1055 ولكن في حالة (ديزل+اوكسيد التيتانيوم) قل من1013 الى 906 عند الحمل الكامل وتركيز25.وقل الدخان مع (ديزل+اوكسيد الالمنيوم) بنسبة 28% ومع (ديزل+اوكسيد التيتانيوم) بنسبة 25% عند نفس الظروف.اما فيما يخص الهايدروكاربونات الغير محترقه زادت مع (ديزل+اوكسيد الالمنيوم) وقلت مع (ديزل+اوكسيد التيتانيوم) الى 8% عند نفس الظروف.

الكلمات المفتاحيه: – الوقود النانوي، حبيبات النانو، العوادم، محرك الديزل.