EFFECT OF MgO NANOPARTICULE ADDITIVES ON PERFORMANCE AND EXHAUST EMMISSIONS OF DIESEL FUELLED COMPRESSION IGNITION ENGINE

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Abstract

Nowadays energy requirements have been rapidly growing due to increasing population and industrialization. Diesel engines have a huge role in environmental pollution. Harmful gas

emissions increase along with energy consumption, therefore, new ways to restrict harmful gases and to take precautions are sought. In this study, MgO nanoparticle additive with extra oxygen content were used in diesel fuel in compression ignition engines, in order to monitor fuel properties, performance and emission values. Dosage of additive into diesel fuel were 25, 50 and 100 ppm and the optimum dosage of additives was determined in relation to decrease of NOx and CO emissions.

Keywords

Compression Ignition Engine, Nanoparticle, Engine performance, Exhaust emission, MgO

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 and other organic and inorganic pollutants including trace metals and their adverse effects on human and environmental health (Barman et. al., 2010). Due to the growing concern over possible adverse health effects caused by diesel emissions, the pollutants have been regulated by law in many developed countries (Chao, Lin, Chao, Chang & Chen, 2001). Diesel engines have the advantages of better fuel economy, lower emissions of HC and CO. However, diesel engines suffered from high emissions of PM and NOx, and it is hard to reduce them simultaneously (Yanfeng, Shenghua, Hejun, Tiegang, & Longbao, 2007). To achieve substantial reductions in emissions, it is thought that reformulated diesel fuels will play an important role. The reformulation of diesel fuels could include lowering the sulfur content, lowering the aromatic content, or potentially the addition of oxygen within the fuel (Ying, Longbao, & Hewu, 2006). It has been shown that many oxygenates are effective in reducing emissions from diesel engines (Neeft, Makkee, & Moulijn, 1996; Grabowski, & McCormick, 1998; Choi, & Reitz, 1999; Beatrice, Bertoli, Del Giacomo, & Migliaccio, 1999).

Oxygenates such as dimethyl ether (DME), dimethyl carbonate (DMC), dimethoxy methane (DMM) methanol, ethanol etc. have been widely studied. Chapman, Boehman, Tijm & Waller, (2001) studied the effects of diesel-DME blends on engine's emissions characteristics and their investigations showed that the emission of PM decreases with the increase of CO, and there is a small NOx reduction for some operating conditions [9]. Bai, Zhou, & Wang, (2002) found that DMC can reduce PM and NOx simultaneously when EGR was adopted. Maricq, Chase, Podsiadlik, Siegl, & Kaiser, (1998) carried out investigations on DMM and their studies

showed that the addition of DMM causes a shift in the PM size distribution to smaller diameters and substantial PM reduction. There is no change in NOx emissions. Huang et.al., (2005) studied the effect of methanol-oleic-solvent mixture on performance and emission characteristics and they concluded that a flat NOx/smoke trade-off curve existed when the oxygenated blends were used.

2. Experimental Set up

2.1 Materials

The fuel used for the current investigation was a diesel fuel. The fuel additive used in this investigation is oxygen containing MgO nanoparticle that properties was given in the Table 1.1, in the form of commercially available nanoparticle size of 10 to 30 nanometers. The dosing level of the nanoparticle samples (by weight) in the base fuel was 25, 50 and 100 ppm.

Table 1: *Properties of nanoparticles used in the experiments*

Nanoparticle	Symbol	Particule Size (nm)	Purity (%)	Cost ($/g)
Magnesium Oxide	MgO	30	99.9	0.71

2.2 Ultrasonic Processor

The required quantity of the nanoparticle sample required for each dosing level was measured using a precision electronic balance and mixed with the fuel by means of an ultrasonic processor, applying a constant agitation time of one hour to produce a uniform suspension. The modified fuel was utilized immediately after preparation, in order to prevent any precipitate or for sedimentation to occur. Sonic Vibra-Cell VC 750 model ultrasonic processor was used to stir nanoparticles with biodiesel fuel homogeneously in order to obtain modified fuels. Nanoparticles were mixed with rapeseed methyl ester with pulsing time 10 seconds on 10 seconds off and 40% amplitude by means of ultrasonic processor. The analysis of test fuels was conducted at the Çukurova University Mechanical Engineering Department Automotive Engineering Laboratories.

2.3 Fuel Property Devices

Fuel properties as density, viscosity, flash point and pour point of the test fuels were determined according to standard test methods. Tanaka MPC-102L type pour point analyser with an accuracy of ±1 °C for pour point; Tanaka AKV-202 type automatic kinematics viscosity

meter with an accuracy of ±0.01 mm^2/s for determining the viscosity; Kyoto Electronics DA-130 type density meter with an accuracy of ±0.001 g/cm^3 for density measurement, Tanaka APM-7 type flash point analyser with an accuracy of ±0.5 °C for flash point measurement was used for analysing the test fuels.

2.4. Test Engine Set Up

Engine performance tests were conducted on a commercial four cylinder, four-stroke, naturally aspirated, water-cooled direct injection compression ignition engine. Technical specifications of engine were presented in Table 1.2.

Table 2: *Technical specifications of test engine*

Brand	Mitsubishi Canter
Model	4D34-2A
Configuration	In line 4
Type	Direct injection diesel with glow plug
Displacement	3907cc
Bore	104mm
Stroke	115mm
Power	89kW @ 3200rpm
Torque	295Nm @ 1800rpm
Oil Cooler	Water cooled
Air Cleaner	Paper element type
Weight	325kg

A Netfren brand hydraulic dynamometer was used for loading the test engine and TESTO 350 XL gas analyzer was used to measure exhaust gas emissions. Emission data was collected by the help of a computer program. Measurement accuracy of the gas analyzer is ±10 ppm for CO, 1% for CO_2 and ±1 ppm for NOx. Measurement capacity of the device is 0-10000 ppm for CO, 0-50% for CO_2 emission and 0-3000 ppm for NOx. Schematic representation of the experimental setup was presented in Figure 1. Before the tests, the engine was operated for enough time with diesel fuel to reach the operation temperature. Test fuels were tested from 1200 to 3200 rpm with an interval of 200 rpm at full load condition.
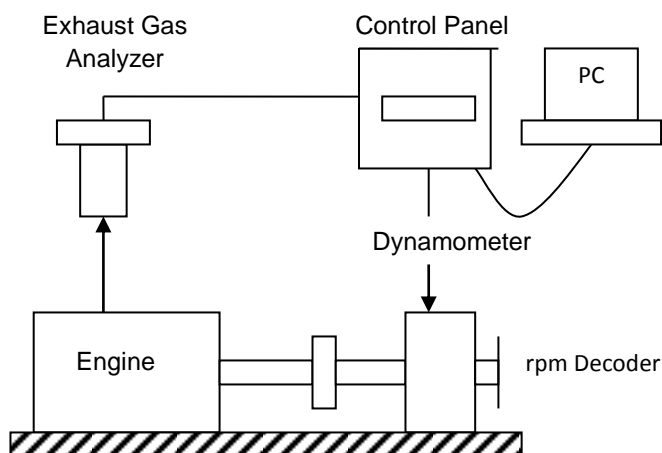
Figure 1: *Schematic representation of the experimental setup*

3. Result and Discussion

3.1 Fuel Properties

The analysis of test fuels was conducted at the Çukurova University Mechanical Engineering Department Automotive Engineering Laboratories. Density, viscosity, flash point, cetane number, pour point characteristic was tested according to standards. Fuel properties of diesel and modified diesel fuels were given in Table 1.3. European diesel standard EN 590 was given in Table 1.3

Table 3: *Fuel Properties of Diesel and Modified Diesel Fuels*

Property	Units	EN 590	Diesel	25 ppm MgO	50 ppm MgO	100 ppm MgO
Density at 15°C	kg/m³	820-845	833	833	834	834
Viscosity at 40°C	mm²/s	2.0-4.5	2.85	2.86	2.88	2.90
Flash point	°C	Min 55	58.5	63.5	63.5	62.5
Cetane number	-	Min 51	56	51.1	45.7	42.6
Pour Point	°C	-	-10	-10	-10	-10

Addition of different dosage of (25, 50 and 100 ppm) MgO nanoparticles has no noticeable effect on density value of diesel fuel. Kinematic viscosity of diesel fuel was not changed considerably with the addition of MgO nanoparticles at the dosage of 25, 50 and 100 ppm. Viscosity value of diesel fuel only increased from 2.85 mm^2/s to 2.86 mm^2/s, 2.88 mm^2/s and 2.90 mm^2/s at the dosage of 25, 50 and 100 ppm MgO nanoparticles additive respectively. All of the viscosity results are in the acceptable range of EN 590. Flash point of the diesel fuel was increased with the MgO nanoparticles addition. At the dosage of 25, 50 and 100 ppm it was increased to 63.5 °C, 63.5 °C and 62.5 °C respectively. The flash point of the fuel gives an indication of the volatility of a fuel. The lower the volatility the higher the flash and fire points. Higher flash point temperatures are desirable for safe handling of the fuel. According to European petrodiesel standard EN 590 for diesel fuel a minimum flash point of 55 °C is required for safety. The flash point result represented that storage and transporting of modified diesel fuels (25, 50 and 100 ppm MgO nanoparticles addition to diesel fuel) can be done safely according to base fuel (diesel fuel). Cetane number of the diesel fuel showed decreasing trend with the addition of MgO nanoparticles. It was decreased to 51.1, 45.7 and 42.6 at the dosage of 25, 50 and 100 ppm MgO nanoparticles addition respectively. Cetane number is the ignition quality of a fuel. Decrease in the cetane number means decrease in the ignition quality of the fuel which will lead to poor combustion of the fuel in the combustion chamber. An adequate cetane number is required for good engine performance. According to European petrodiesel standard EN 590 for diesel fuel a minimum cetane number of 51 is required for good combustion. Cetane number (51.1) of the modified fuel is in the limits of EN 590 when the dosage of MgO nanoparticles addition is 25 ppm. At the dosage of 50 and 100 ppm, cetane numbers (45.7 and 42.6) of the modified fuels are outside of the EN 590 range. The temperature at which crystal formation is extensive enough to prevent free pouring of fluid is determined by measurement of its pour point (PP). If pour point of a fuel is not low enough, some concerns with storing, transferring can occur. Addition of 25, 50 and 100 ppm MgO nanoparticles to diesel fuel did not show significant effect on the pour point.

3.2 Engine Performance

The brake power output of test fuels is shown in Figure 2. Generally, power output values reduced with the increased dosage of MgO nanoparticle addition in the diesel fuel at high engine speeds. The characteristics of power curve were not changed according to dosage of the additive.

It was observed that the maximum power values with all test fuels were obtained at an engine speed of 2400 rpm. The maximum brake power reduction according to diesel fuel result is 12%, 17% and 20% for the modified fuels at the nanoparticle addition dosage of 25, 50 and 100 ppm respectively. The maximum brake power reduction was obtained at 2600 rpm engine speed for the all test fuels. The average reduction is 3.8%, 6.1% and 8.2% according to base fuel (diesel fuel) at the addition dosage of 25, 50 and 100 ppm respectively. The reduction can be resulted from incomplete combustion of the fuel due to low cetane numbers of modified fuels.
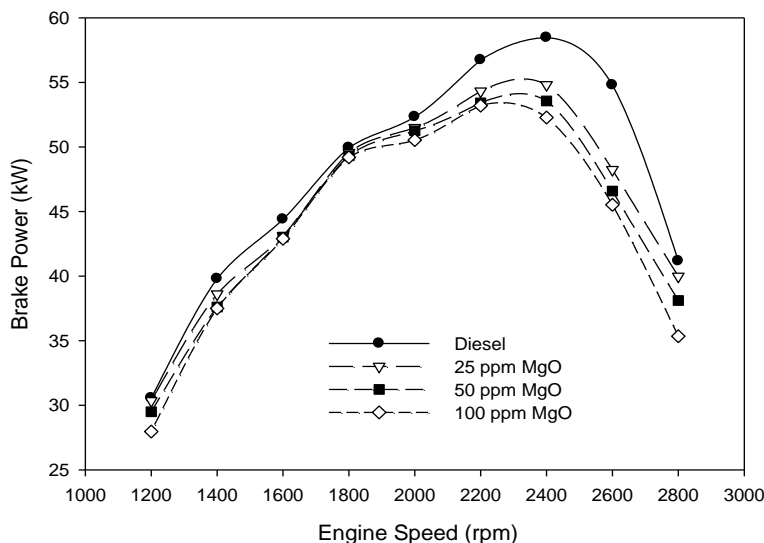

Figure 2: *Brake power output versus engine speed for the test fuels*

The torque output of test fuels is shown in Figure 4. Generally, torque output values reduced with the increased dosage of MgO nanoparticle addition in the diesel fuel. The characteristics of torque curve were not changed according to dosage of the additive. The maximum torque values for all fuels were obtained at an engine speed of 1400-1600 rpm. The maximum torque output reduction according to diesel fuel result is 10%, 13.3% and 17.1% for the modified fuels at the nanoparticle addition dosage of 25, 50 and 100 ppm respectively. The value of the torque reduction amount is higher at high engine speeds (average 13.4 % at 2600 rpm) than that of at lower engine speeds (average 2.2 % at 1200 rpm). The maximum torque reduction was obtained at 2600 rpm engine speed for the all test fuels. The average reduction is 4.5%, 5.5% and 6.4% according to base fuel (diesel fuel) at the addition dosage of 25, 50 and 100 ppm respectively.
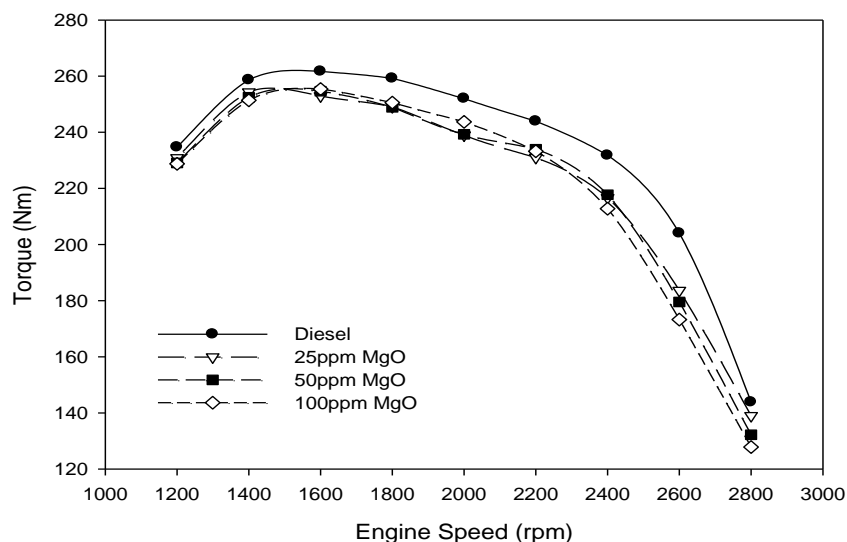
Figure 4: *Torque output versus engine speed for the test fuels*

The variation in specific fuel consumption (SFC) with engine speed for test fuels is presented in Figure 5. Minimum SFC values of the test fuels were measured at the engine speed range of 2400 rpm where the maximum engine power was obtained. The SFC values of the modified fuels (25, 50 and 100 ppm MgO nanoparticles addition to diesel fuel) with respect to base fuel (diesel fuel) were decreased at higher engine speed especially between 2400 and 2800 rpm and increased at lower engine speed particularly between 1200 and 1800 rpm. The maximum specific fuel consumption reduction according to diesel fuel result is 3.3%, 4.8% and 6.7% for the modified fuels at the nanoparticle addition dosage of 25, 50 and 100 ppm respectively at the engine speed of 2800 rpm. The maximum increment is 0.8%, 2% and 5.8% at the addition dosage of 25, 50 and 100 ppm respectively at the engine speed of 1400 rpm. The average change in the SFC values of all the test fuels is under 0.6 % which refers to there is not noticeable change in the SFC values averagely.
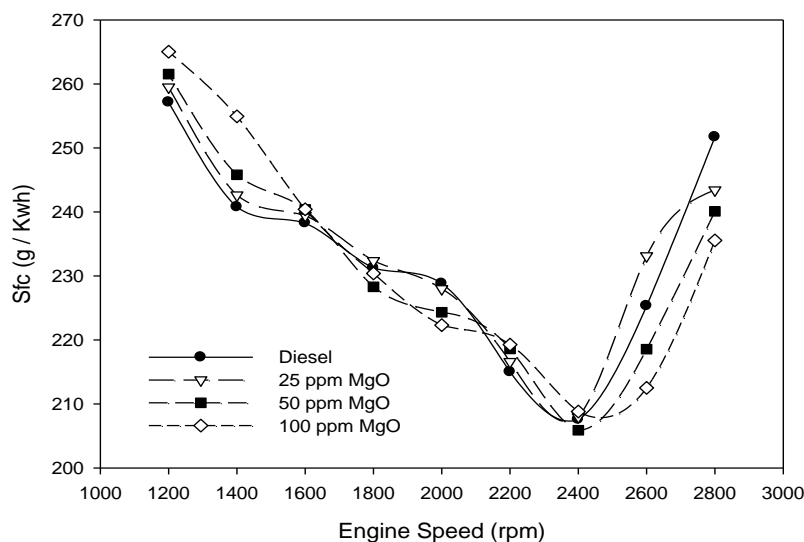
Figure 5: *Specific fuel consumption versus engine speed for the test fuels*

3.3 Exhaust Emissions

Figure 6 demonstrates the carbon monoxide (CO) emissions versus engine speed with the variation of additive dosage. In comparison with diesel fuel, CO emission values of modified fuels (50 and 100 ppm MgO nanoparticles addition to diesel fuel) was increased at high engine speeds (2000-2800 rpm) and decreased at lower engine speeds for all modified fuels (25, 50 and 100 ppm MgO nanoparticles addition to diesel fuel). The maximum CO emission reduction according to diesel fuel result is 17.6%, 30.6% and 28% for the modified fuels at the nanoparticle addition dosage of 25, 50 and 100 ppm respectively. The maximum CO emission reduction was obtained at 1200 rpm engine speed for the all test fuels. The maximum average reduction is 12.2% according to base fuel (diesel fuel) at the MgO nanoparticle addition dosage of 25 ppm.
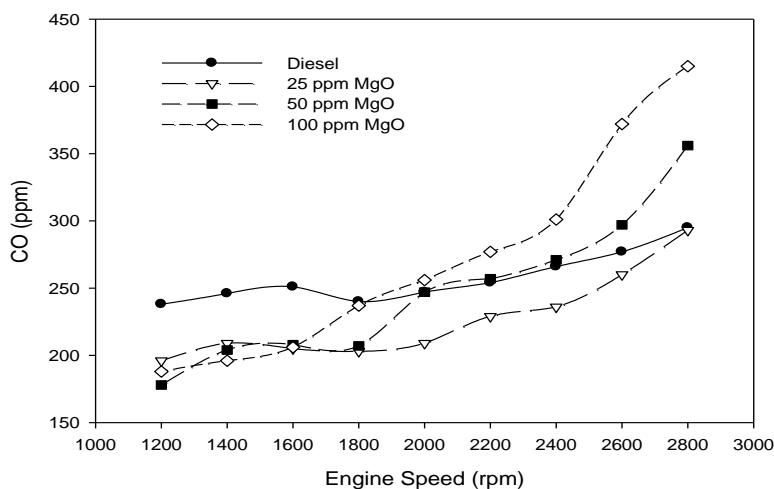
Figure 6: *CO emission values of test fuels*

Figure 7 illustrates carbon dioxide (CO_2) emissions of test fuels at different engine speeds. The maximum CO_2 emissions were measured with diesel fuel. CO_2 emissions were reduced with the increase in the dosage of the MgO nanoparticle addition. The maximum carbon dioxide emission reduction according to diesel fuel result is 6%, 8.5% and 29.4% for the modified fuels at the nanoparticle addition dosage of 25, 50 and 100 ppm respectively. The maximum carbon dioxide emission reduction was obtained at 2800 rpm engine speed for the all test fuels. The average reduction is 1.9%, 6.6% and 13.6% according to base fuel (diesel fuel) at the addition dosage of 25, 50 and 100 ppm respectively.
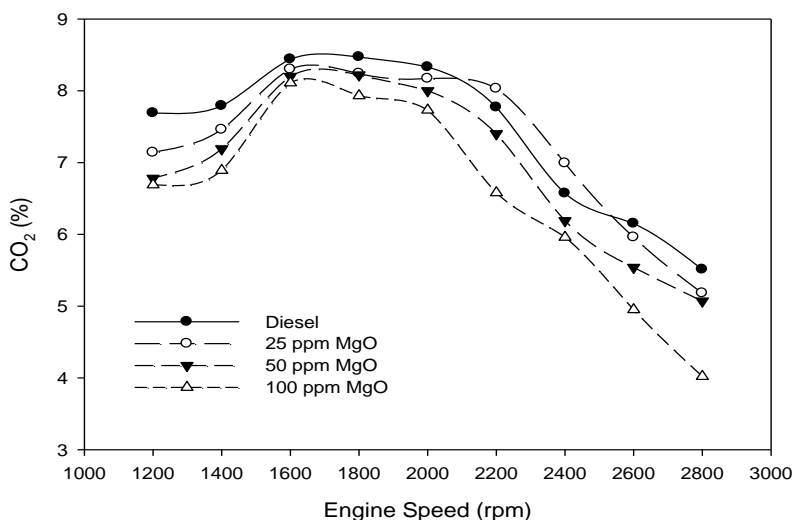

Figure 7: *CO_2 emission values of test fuels*

The variations of measured nitrogen oxides (NO_x) emissions values of test fuels with engine speed are demonstrated in the Figure 8. The maximum NO_x emissions were measured with diesel fuel. NO_x emissions were reduced with the increase in the dosage of the MgO additive. The maximum nitrogen oxides emission reduction according to diesel fuel result is 4%, 12.3% and 37% for the modified fuels at the nanoparticle addition dosage of 25, 50 and 100 ppm respectively. The maximum nitrogen oxides emission reduction was obtained at 2800 rpm engine speed for the all test fuels. The average reduction is 3.1%, 8.9% and 16.7% according to base fuel (diesel fuel) at the addition dosage of 25, 50 and 100 ppm respectively. The reductions in NO_x emission is due to complete combustion of modified fuels with the help of catalyst effect of MgO nanoparticle addition which promotes heat transfer in the combustion chamber.
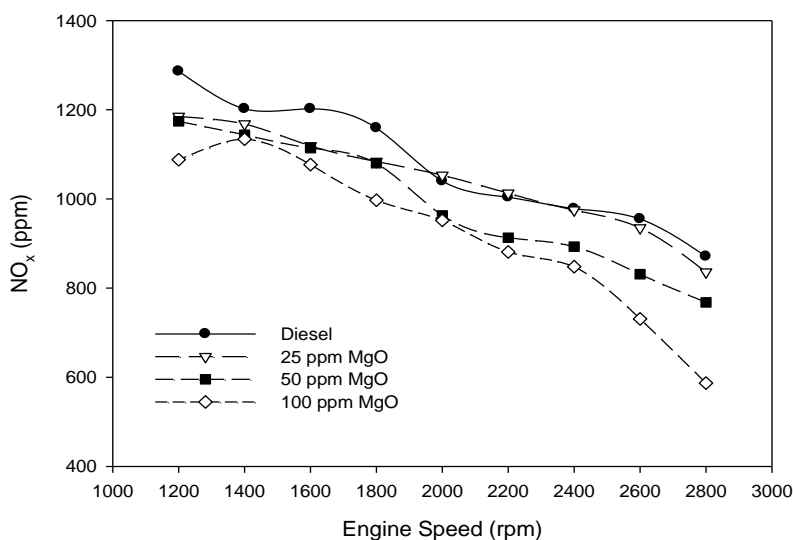

Figure 8: *NO$_x$ emission values of test fuels*

4. Conclusions

The density and pour point of diesel fuel does not show significant variation, due to the addition of MgO nanoparticle. The viscosity of diesel fuel was slightly increased with the addition of MgO nanoparticle. Engine performance tests with diesel fuel and modified diesel fuel at different dosing levels (25, 50 and 100 ppm) of the additives showed a slightly decrease in the torque and brake power output values of the test engine.

The maximum CO emission reduction according to diesel fuel result is 17.6%, 30.6% and 28% for the modified fuels at the nanoparticle addition dosage of 25, 50 and 100 ppm

respectively. The maximum CO emission reduction was obtained at 1200 rpm engine speed for the all test fuels. The maximum average reduction is 12.2% according to base fuel (diesel fuel) at the MgO nanoparticle addition dosage of 25 ppm. Combustion remains incomplete due to two reasons, insufficient quantity of air supplied and lesser time allowed for completion of combustion process. Oxygen containing nanoparticle decrease the CO emissions of the biodiesel fuel by supplying extra oxygen to the fuel-air mixture in the combustion chamber.

CO_2 emissions were reduced with the increase in the dosage of the MgO nanoparticle addition. The average reduction is 1.9%, 6.6% and 13.6% according to base fuel (diesel fuel) at the addition dosage of 25, 50 and 100 ppm respectively.

NO_x emissions were reduced with the increase in the dosage of the MgO additive. The average reduction is 3.1%, 8.9% and 16.7% according to base fuel (diesel fuel) at the addition dosage of 25, 50 and 100 ppm respectively. The reductions in NO_x emission is due to complete combustion of modified fuels with the help of catalyst effect of MgO nanoparticle addition which promotes heat transfer in the combustion chamber.

Table 4: *Reduction in the engine performance and emissions of diesel fuel*

Additive	Dosing Level	Torque	Brake P.	CO	CO_2	NO_x	Cost (TL/Liter)
MgO	25 ppm	4.5%	3.8%	12%	2%	3%	0.022

As a result of the study, MgO nanoparticles at the addition dosage of 25 ppm can be used as additive with a low extra cost for the diesel fuel to decrease the exhaust emissions of diesel engines as shown in Table 1.4.

5. Acknowledgements

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