Influence of NiFe$_2$O$_4$ and Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$ nanoparticles on exhaust emissions of 4 stroke-6 cylinders turbocharged diesel engine

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Diesel vehicles have a huge role in the transportation of goods and people however they cause air pollutions. For this reason, researchers try to find alternative fuel additives to decrease the exhaust emissions. This experimental work focus on the impacts of oxygen content nanoparticle additives on exhaust emissions of 4 Stroke-6 cylinders turbocharged diesel engine fuelled with diesel fuel. Nickel iron oxide and nickel zinc iron oxide nanoparticles with the dosage of 15, 20 and 25 ppm were used as additives in the experimental tests. According to the results, the optimum dosage level of nanoparticles was found. As finally, the results revealed that the exhaust emission values were decreased with the nanoparticle addition to diesel fuel.

Keywords: Nanoparticle; nickel iron oxide; nickel zinc iron oxide; exhaust emissions; diesel engine

1. Introduction

Petroleum resources have a huge role in energy demanding. However, the depletion of petroleum fuels is increasing rapidly [1]. In the world diesel engines are mostly used in motor vehicles, automobiles, manufacturing power generation, farming [2-3]. Diesel vehicles induced to the many air pollutants like carbon monoxide, carbon dioxide, hydrocarbons, particulate matter, nitrogen oxides and soot emissions [4-5]. Due to the economic and environmental concerns have led to the find alternative fuel for diesel engine [6]. Various fuel additives are used in order to beat adverse effects of diesel fuel [7-8]. According to many research studies that adding nanoparticle to diesel and biodiesel fuels improve combustion efficiency and reduction exhaust emissions [9-11]. Many researchers used metal-based additives which posses’ desirable properties such as high thermal conductivity, surface-volume ratio, and better ignition characteristics [12]. There are many nano additives such as zinc oxide, manganese, carbon nanotube, cerium oxide, iron oxide, alumina, copper oxide, titanium oxide, magnesium oxide [3,7,13].

Rastogi et. al [12] carried out experimentally study to find the effects of CuO nanoparticles on performance of diesel engine, emission and combustion characteristics which runs on jojoba
biodiesel blend (JB20) as a fuel. They added 25, 50 and 75 ppm CuO to JB20. They observed that BTE for the JB20CN50 fuel was higher than that of other Jojoba biodiesel fuel samples and engine emission hydrocarbons, CO and smoke emissions were also found lesser when the CuO nanoparticles added to JB20.

Srinidhi et. al [13] investigated the impacts of NiO nanoparticle doped azadirachta indica biodiesel-diesel fuel (NBE25) blend on CI engine performance at different fuel injection timing. Nickel oxide nanoparticle concentration was 25, 50, 75 and 100 ppm in NBE25 base fuel. According to the outcomes there is an important reduction on HC and CO emissions for the nickel oxide mixed biodiesel compared with a biodiesel blend (NBE25).

Özgür et. al. [14] had examined the engine performance and emission parameters of diesel engine by using SiO$_2$ and MgO nanoparticles mixed with rapeseed biodiesel. Nano particles were added to biodiesel with mass fractions of 25 and 50 ppm. According to the results, they observed a reduction in NO$_x$ and CO emission values and engine performance increased with the addition of SiO$_2$ and MgO nanoparticle additives.

Mehregan and Moghiman [15] explored the effects of nano additives on performance and emission characteristics of diesel engine equipped with urea-SCR system fuelled with blended biodiesel fuel. They used manganese oxide and cobalt oxide as nanoparticle additives at the dosage of 25 and 50 ppm. They found that the brake specific fuel consumption and the brake thermal efficiency increased with the addition of nanoparticles and they observed reduction in the NO$_x$ and CO emissions compared to those of base fuel.

Kumar et. al. [16] studied the emission behaviour of four stroke, single cylinder, diesel engine fuelled diesel fuel adding with TiO$_2$ nanoparticle. They added 50 and 100 ppm TiO$_2$ nanoparticle to diesel fuel. They observed that adding 50 and 100 ppm of TiO$_2$ nanoparticles to diesel, significant reduction in CO, HC, NO$_x$, and smoke emissions.

The goal of this experimental work is to examine the influence of Nickel Iron Oxide and Nickel Zinc Iron oxide in diesel fuel as an additive to determine the exhaust emissions in 4 Stroke-6 cylinder turbocharged diesel engine.

2. Experimental Set up

In this experimental study, diesel was used as fuel. Nickel iron oxide and nickel zinc iron oxide nanoparticle additives which are commercially available with size 30 nanometers were used to prepare fuel blends. The amount of nanoparticles that are required for all level of doses were measured using electronic precision scales with sensitivity of 0.0001 g. The chosen dosage levels of nanoparticles were 15, 20 and 25 ppm. Nickel iron oxide and nickel zinc iron oxide nanoparticles added to diesel fuel with Sonic Vibra-Cell VC 750 model ultrasonic processor during half an hour to obtain a homogeneous fuel mixture. These test fuels were used in order to prevent any precipitation without delay. The properties of nanoparticles are given Table 1.

| Nanoparticle          | Symbol       | Particle Size (nm) | Purity (%) |
|-----------------------|--------------|--------------------|------------|
| Nickel Iron Oxide     | NiFe$_2$O$_4$| 30                 | 99.9       |
| Nickel Zinc Iron Oxide| Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$ | 30 | 99.5 |

The measured fuel properties are density, kinematic viscosity, cetane number and pour point. Table 2 represents the specifications of fuel properties measurement devices.

| Property               | Device         | Accuracy             |
|------------------------|----------------|----------------------|
| Density (kg/m$^3$)     | Kyoto Electronics DA-130 | ±0.001 g/cm$^3$ |
| Kinematic viscosity (cSt) | Tanaka AKV-202    | ±0.01 cSt            |
| Cetane number          | Zeltex ZX 440  | ±0.5                 |
| Pour Point (°C)        | Tanaka MPC 102L | ±1 °C                |

In this work, a 6-cylinder, 4 stroke, turbocharged and charge air cooled intercooled diesel engine which was run on a hydraulic dynamometer is used. The technical properties of engine test show on Table 3. Lay out of the system was demonstrated in Figure 1. The experimental tests were conducted at full load condition between 1400 and 2200 rpm, with an interval of 200 rpm. AVL SESAM Fourier Transform Infrared Spectroscopy (FTIR) multi-component exhaust analyser were used to measure exhaust emission concentrations. The
accuracy of the measurements is 0.01 for all types of exhaust emissions. In the after treatment process, selective catalytic reduction, which involves the spraying of urea in the tail pipe, was incorporated to mitigate NO$_x$. The engine is equipped with SCR aftertreatment system. The specifications of catalyst used in SCR system are shown in Table 4.

![Figure 1. Lay out of the system](image)

Table 3. Characteristics of test engine

| Specifications | Descriptions |
|----------------|--------------|
| Manufacturer/series type | Cummins ISBE4+250B Electronic control system, 4 stroke, 6 cylinder, Turbocharger & aftercooled |
| Engine type | Electronic control system, 4 stroke, 6 cylinder, Turbocharger & aftercooled |
| Bore | 107 mm |
| Stroke | 124 mm |
| Compression ratio | 17.3 |
| Displacement | 6700 cc |
| Power | 184 kW@2500 rpm |

Table 4. Specifications of the catalyst in Aftertreatment system

| Specifications | Descriptions |
|----------------|--------------|
| Diameter (m) | 0.2667 |
| Length (m) | 0.3048 |
| Cell Geometry | Honeycomb type square celled catalyst |
| Total Volume (L) | 17 |
| Cell Density/m$^2$ | 400 |
| Cell Width (mm) | 1.2 |
| Open Frontal Area (m) | 1.86 |
| Wall Thickness (mm) | 0.105 |
| Thermal conductivity (W/m·K) | 0.4 |

3. Results and Discussion

3.1. Fuel properties

Density, viscosity, cetane number and pour point values were measured according to the standards. The fuel properties of diesel fuel and test fuels are demonstrated in Table 5.

According to the table, density and pour point of diesel fuel does not show important variation, with the addition of nanoparticles to diesel fuel. The viscosity of diesel fuel was slightly increased with the addition of nanoparticles to diesel fuel. Cetane number of the test fuels decreased with the addition of nanoparticles. 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 [17].

![Figure 2. NO$_x$ emissions of test fuels versus engine speed.](image)

3.2. NO$_x$ Emissions

Figure 2 is given NO$_x$ emissions of test fuels versus engine speed. The chosen addition dosage of NiFe$_2$O$_4$ nanoparticle is 15, 20 and 25 ppm. As the nanoparticle dosage increased, a reduction in the emission values was observed. The percentage alteration of NO$_x$ emissions of test fuels compared to neat diesel fuel is given in Figure 3. According to the results, the average reduction is 5.5%, 7.4% and 8.5% for the addition dosage of 15, 20 and 25 ppm respectively.

The variations of NO$_x$ emission values of Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$-diesel fuel blends with different engine speed is demonstrated in Figure 4. According to the results the maximum reduction in NO$_x$ emissions was measured with modified fuel with the Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$ addition dosage of 25 ppm. The maximum nitrogen oxides emission decrease was acquired at 2200 rpm engine speeds for the all test fuels. The average reduction in NO$_x$ emission is 2.3 %, 3.2 % and 4.7 % with respect to neat diesel at the addition.
Table 6. The changes in NOx emissions with the addition of nanoparticles to diesel engine

| rpm   | Diesel | 15 ppm NiFe$_2$O$_4$ | 20 ppm NiFe$_2$O$_4$ | 25 ppm NiFe$_2$O$_4$ |
|-------|--------|----------------------|----------------------|----------------------|
| 1400  | 1128.0000 | 1041.0000             | 1035.0000             | 1023.0000             |
| 1600  | 998.0000   | 978.0000              | 970.0000              | 962.0000              |
| 1800  | 939.0000   | 918.0000              | 872.0000              | 863.0000              |
| 2000  | 865.0000   | 830.0000              | 805.0000              | 800.0000              |
| 2200  | 828.0000   | 732.0000              | 728.0000              | 712.0000              |

Table 6 gives the changes in NOx emissions with the addition of nanoparticle to diesel fuel at different engine speeds.

dosage of 15, 20 and 25 ppm respectively. The reason of the reductions in NOx emission of diesel fuels with the addition nanoparticles is complete combustion of oxygenated fuel blends with the help of catalyst effect of nanoparticle additions which promotes heat transfer in the combustion chamber due to their metallic-base structures [18].

Figure 2. Experimental NOx emission data to NiFe$_2$O$_4$-diesel

Figure 3. Percentage alteration of NOx emissions of test fuels compared to diesel fuel

3.3. CO Emissions

Figure 6 presents the carbon monoxide (CO) emissions of modified fuel blends. It is observed that CO emissions are decreased with the addition of NiFe$_2$O$_4$ nanoparticle to diesel fuel. Figure 7 shows percentage alteration of CO emissions of test fuels compared to neat diesel fuel. The average reduction in CO emission with
Table 7. The changes in CO emissions with the addition of nanoparticles to diesel engine

| rpm  | Diesel | 15 ppm NiFe2O4 | 20 ppm NiFe2O4 | 25 ppm NiFe2O4 |
|------|--------|----------------|----------------|----------------|
| 1400 | 88     | 85.0000        | 82.0000        | 79.0000        |
| 1600 | 77     | 74.0000        | 71.3000        | 70.0000        |
| 1800 | 125    | 118.0000       | 110.0000       | 105.8000       |
| 2000 | 402    | 395.0000       | 382.0000       | 378.2000       |
| 2200 | 439    | 418.0000       | 411.0000       | 407.8000       |

Zn0.5Ni0.5Fe2O4-diesel fuel blends

| rpm  | Diesel | 15ppm Zn0.5Ni0.5Fe2O4 | 20ppm Zn0.5Ni0.5Fe2O4 | 25ppm Zn0.5Ni0.5Fe2O4 |
|------|--------|-----------------------|-----------------------|-----------------------|
| 1400 | 88     | 86                    | 83                    | 78                    |
| 1600 | 77     | 76                    | 75                    | 73                    |
| 1800 | 125    | 111                   | 108                   | 105                   |
| 2000 | 402    | 399                   | 395                   | 386                   |
| 2200 | 439    | 435                   | 431                   | 428                   |

The changes in CO emissions with the addition of nanoparticles to diesel engine respect to neat diesel result 3.9%, 7.5% and 9.5% with respect to diesel at the NiFe2O4 nanoparticle addition dosage of 15, 20 and 25 ppm respectively.

Figure 6. CO emissions of NiFe2O4-diesel blends at different engine speeds

Figure 7. Percentage alteration of CO emissions of test fuels compared to diesel fuel

Figure 8 shows the carbon monoxide (CO) emissions of Zn0.5Ni0.5Fe2O4-diesel fuel blends at different engine speeds. According to the results nanoparticle addition dosage of 15, 20 and 25 ppm decreased the CO emissions with respect to diesel fuel. The maximum CO emission reduction was get at between 1400 and 1800 rpm engine speed. The average reduction is 3.3%, 5.1% and 7.8% with respect to diesel at the addition dosage of 15, 20 and 25 ppm respectively. The reason for the carbon monoxide emission is incomplete combustion, which is raised by a lack of oxidants, residence time, and temperature. The CO emissions
decrease slightly with the use of nanoparticle additives. This may be owing to the catalytic activity of nanoparticles and improving the fuel–air mixing in the combustion chamber, and in turn resulting in reduced CO emissions [19]. Table 7 shows the changes in CO emissions with the addition of nanoparticle to diesel fuel at different engine speeds.

### 3.4. HC Emissions

The hydrocarbon (HC) emissions of modified test fuels is given in Figure 10. NiFe$_2$O$_4$ nanoparticle additive amount of 15, 20 and 25 ppm decreased the HC emissions values of the diesel fuel. Figure 11 gives percentage alteration of HC emissions of test fuels compared to neat diesel. The average reduction in HC emissions is 3.3%, 4.4% and 5.2% with respect to neat diesel at the NiFe$_2$O$_4$ nanoparticle addition dosage of 15, 20 and 25 ppm respectively.

![Figure 10. Impacts of NiFe$_2$O$_4$-diesel blends on HC Emission](image)

![Figure 11. Percentage alteration of HC emissions of test fuels compared to diesel fuel](image)

Hydrocarbon emission values of test fuels at different engine speeds are given in Figure 12.

![Figure 12. Effect of Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$-diesel blends on HC emission](image)

![Figure 13. Percentage alteration of HC emissions of test fuels compared to diesel fuel](image)

Table 8 demonstrates the changes in HC emissions with the addition of nanoparticle to diesel fuel at different engine speed.

### 4. Conclusions

In this experimental study the effects of NiFe$_2$O$_4$ and Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$ nanoparticle additive decreased the HC emissions values of the diesel fuel. The average reduction is 2.8%, 3.6% and 5.4% according to neat diesel at the Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$ nanoparticle addition dosage of 15, 20 and 25 ppm respectively. The average reduction in HC emission values decreased with the increased dosage of Zn$_{0.5}$Ni$_{0.5}$Fe$_2$O$_4$ nanoparticle addition to diesel fuel. HC emissions contribute to the formation of smog and may include photochemically reactive species as well as carcinogens. Nano additive addition has been shown to decrease HC emissions. Reduction in HC emissions may be due to secondary atomization, shorten ignition delay, and catalytic activity of nano additives leading to better combustion [20].
and Zn0.5Ni0.5Fe2O4 nanoparticle addition to diesel fuel on exhaust emissions of 4 Stroke-6 cylinder turbocharged diesel engine. The results are given below:

- The NOx emission values decrease with the addition both nanoparticle additives. However, NiFe2O4 shows better effect in reducing NOx emissions.

- The maximum reduction on CO emission was achieved with NiFe2O4 nanoparticle addition at the dosage level of 25 ppm to diesel fuel.

- HC emissions of diesel were obtained to decrease with the addition of NiFe2O4 and Zn0.5Ni0.5Fe2O4 nanoparticles. The maximum reduction was found Zn0.5Ni0.5Fe2O4 nanoparticle at the addition dosage level of 25 ppm as 5.4 %.

- Overall NiFe2O4 and Zn0.5Ni0.5Fe2O4 nanoparticle addition to diesel fuel decreases the exhaust emissions this may be due to the in promoting fuel atomization and its favorable intrinsic catalytic effect, the level of harmful pollutants (such as HC, CO, NOx) in exhaust gases is appreciably reduced to varying degrees [21].

### Nomenclature

- **NiFe2O4**: nickel iron oxide
- **Zn0.5Ni0.5Fe2O4**: nickel zinc iron oxide
- **SCR**: Selective catalytic reduction
- **NOx**: nitrogen oxide
- **CO**: carbon monoxide
- **HC**: hydrocarbon

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