INVESTIGATION OF THE EFFECTS ON ENGINE PERFORMANCE AND EMISSIONS OF $ZnFe_2O_4$ AND $ZnCO_3$ NANOPARTICLE ADDITIVES IN A DIESEL ENGINE

by

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In this study, engine performance and emissions effects of $ZnFe_2O_4$ *and* $ZnCO_3$ *nanoparticle additives have been investigated in a Diesel engine. The experiments have been carried out at 600 rpm and different loads (250-380 Nm) in a 11670 cc heavy-duty Diesel engine. Mixtures of additives have been applied to diesel fuel as 100 ppm. Brake thermal efficiency, cylinder pressure, and emission values have been tested for all investigated fuel mixtures. The maximum thermal efficiency values of D-*$ZnCO_3$*-100 and D-*$ZnFe_2O_4$*-50 are higher than diesel fuel. Also, CO emission values of D-*$ZnCO_3$*-100 and D-*$ZnFe_2O_4$*-50 are obtained as less than diesel fuel.*

Key words: *nanoparticles, diesel fuel, emissions, combustion*

Introduction

Hydrocarbon fuels release CO, unburned hydrocarbon, NO_x, particle material emissions, *etc.* Nanoparticles are added to reduce unwanted emissions and to improve diesel fuels. So, it is preferred high thermal properties in nanodiesel applications to get better combustion in the engine and to enhance the combustion efficiency [1-8]. Also, there are many studies on different blends fuels as diesel-acetyone, diesel-fuel-oil, diesel-ethanol, *etc.* [9-21]. Alumina (Al_2O_3), [3, 6, 7, 22-31], copper oxide (CuO) [8, 31-36], and zinc oxide (ZnO) nanoadditives [37-41] have improved engine performance and emissions.

It was observed that when 25 ppm Al_2O_3 was added to the mixtures of 20% biodiesel, 70% diesel, and 10% ethanol, it is improving combustion, engine performance and emissions [3]. It was emphasized that 30 ppm, 60 ppm, and 90 ppm Al_2O_3 was mixed in 20% biodiesel and 80% diesel, and specific fuel consumption decreased, engine performance and emissions improved [4]. It has been tested that when Al_2O_3 nanoadditives are mixed with 20% biodiesel, emissions and fuel consumption decrease and maximum in-cylinder pressure increases. The best performance is stated as 100 mg/L [5]. Dhahad *et al.* [6] 25 ppm, 50 ppm, 100 ppm, and 150 ppm Al_2O_3 and TiO_2 nanoparticles were mixed with diesel fuel and tested, cylinder pressure, efficiency, and emissions were improved. Cinar and Akyuz [7] investigated the effect of engine performance and exhaust emissions when Cu_2O and Al_2O_3 nanoparticles were added to diesel fuel as 50 ppm and 100 ppm. In their experiment, they observed that the nanoparticles exhibit different properties under different load conditions and the benefit increased as the load increased.

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Rastogi *et al.* [8] obtained the best result as 50 ppm in their experiments by mixing 25 ppm, 50 ppm, and 75 ppm CuO nanoparticles into 20% biodiesel and 80% diesel mixtures. Comparative experiments were conducted to reduce the emission of Diesel engines operating with hydrogen fuel mixtures of TiO_2, CNT, Al_2O_3, CuO, and CeO_2 100 ppm nanoadditives. It was determined that CNT had the best performance [31]. Perumal and Ilangkumaran [32] observed that with the addition of CuO, the efficiency increased by 4.01%, reduced NO_x emission by 9.8% and smoke emission by 12.8%. Devarajan *et al.* [33] studied on CuO nanoparticles and blended biodiesel. They measured engine performance and emission variations in Diesel engine. They stated that the CuO nanoparticle inclusion at 20-nm nanoparticle in biodiesel further improves the performance parameters than those at 10-nm nanoparticle. Venkataswamy *et al.* [34] investigated on CuO/Zn-CeO_2 nanocomposite for catalytic soot oxidation. They stated that pure CuO/ZnO and CuO/CeO_2 catalysts showed a soot oxidation activity with a T50 (T50, where 50% of soot converted to CO_2) of 613 °C and 526 °C, respectively, under the practical conditions of NO concentration of 500 ppm and 20% O_2.

Dharmaprabhakaran *et al.* [42] investigated the engine performance values by mixing 25 ppm, 50 ppm, 75 ppm, and 100 ppm Al_2O_3 into a mixture of 20% biodiesel + 80% diesel. In studies, they obtained the best performance at 100 ppm. Kolakoti [22] added 50 ppm and 100 ppm Al_2O_3 to diesel fuel by mixing it with 10% and 20% biodiesel. At 75% and 100% loads, the useful works of B10 50 ppm, B10 100 ppm, B20 50 ppm, and B20 100 ppm are higher than that of B10 and B20 fuel, and the useful works are close to each other at 50 ppm and 100 ppm blends.

There are several other types of additives that are commonly used in diesel fuel to improve performance and reduce emissions. One example of a diesel fuel additive is cetane improver, which is added to improve ignition quality and combustion efficiency. Cetane improvers are typically organic compounds that contain nitrogen, such as alkyl nitrates or peroxides.

Although TiO_2, Al_2O_3, and CuO nanoparticles are widely used in the literature, the data on zinc compositions additives are limited. In this study, the performance and emission values of additive fuels with zinc composition $ZnCO_3$ and $ZnFe_2O_4$ additives in diesel engines are compared. Thus, the performance and emission values of these fuels with zinc composition in diesel engines will contribute to the literature.

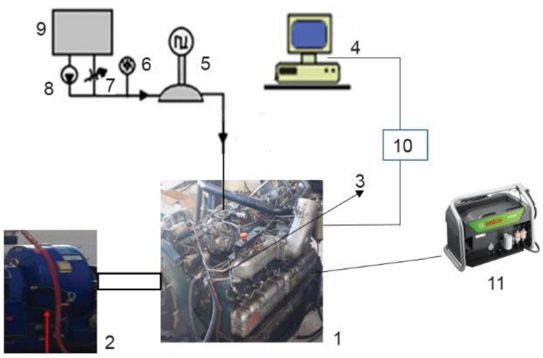

Figure 1. Experimental set-up; *1 – engine, 2 – eddy current, 3 – manometer, 4 – computer, 5 – fuel flowmeter, 6 – fuel manometer, 7 – valve, 8 – fuel pump, 9 – fuel tank, 10 – pressure gauge, 11 – emission meter*

Materials and methods

Experimental set-up

The experimental set-up of the study is given in fig. 1. The engine used in this experiment is a six cylinders direct injection, 11670 L, water-cooled heavy-duty engine at Erciyes University Laboratory. The engine specification is given at tab. 1. The dynamometer is eddy current and has a measurement capability of 10000 rpm and 600 Nm. In-cylinder pressures were measured with the PCB 113B22 piezoelectric pressure transducer. The CO, CO_2, HC, and NO emission measurements were made with BOSCH BEA 60 device. As a result, the Brettschneider formula was used to compute the EAR in the tests [43]. The experiments were carried out at 600 rpm in the range of 250-350 Nm torque (65-100% load).

Preparation of test fuels

The $ZnCO_3$ and $ZnFe_2O_4$ nanoadditives were mixed into the fuel at 50 and 100 ppm. The specifications of these nanoadditives are seen at tab. 2. Nanoparticles dimensions are between 8 and 28 nm. $ZnCO_3$ has the most specific surface area. In this study, there are five different fuels with different loads. Table 3 illustrates the types of fuel mixtures used in the experiments.

Table 1. Engine specifications [10, 44]

Engine	A heavy-duty diesel engine
Bore	133 mm
Stroke	140 mm
Number of cylinders	6
Displaced volume	11670 L
Maximum power	234 Hp
Maximum speed	2300 rpm
Compression ratio	16.0
Injection timing	16° bTDC
Nozzle opening pressure	200 kg/cm^2 (2850 psi)
Firing order	1–4–2–6–3–5
Valve clearance (COLD)	In. 0.4 mm, Exh. 0.4 mm

Table 2. Physical properties of $ZnFe_2O_4$ and $ZnCO_3$

	$ZnCO_3$	$ZnFe_2O_4$
Purity	99,95	98,7
Color	White	Brown
Density [gcm^{-3}]	4.39	5.2
Melting point [°C]	250-300	1200-1300 °C
Average particle size [nm]	18	8-28
Specific surface area [m^{2}g^{-1}]	85	54
Elemental analysis	(SO_4 0.35%) (Zn 58.0%) (Pb 0.0003%) (Cu 0.0001%) (Cd 0.0001%)	(Si 40 ppm) (Na 1800 ppm) (Mn 1300 ppm) (Co 20 ppm) (Ca 320 ppm) (Others 300 ppm)

Table 3. Different fuel types used in the experiments

Mode	Tested Fuels
Diesel	Only diesel
D-$ZnCO_3$-50	Diesel and 50 ppm $ZnCO_3$
D-$ZnCO_3$-100	Diesel and 100 ppm $ZnCO_3$
D-$ZnFe_2O_4$-50	Diesel and 50 ppm $ZnFe_2O_4$
D-$ZnFe_2O_4$-100	Diesel and 100 ppm $ZnFe_2O_4$

An ultrasonic mixer was used to mix the nanoadditives into diesel fuel homogeneously. Nanoadditive particles were weighed as 0.1 g and mixed with diesel oil in an ultrasonic blender, fig. 2. Fuel and nanoparticle additives were mixed for 90 minutes.

Results and discussion

Efficiency, CO, NO, and HC emissions, in-cylinder pressure values and heat release changes of nanoadditives of $ZnCO_3$ and $ZnFe_2O_4$ in diesel engine were investigated.

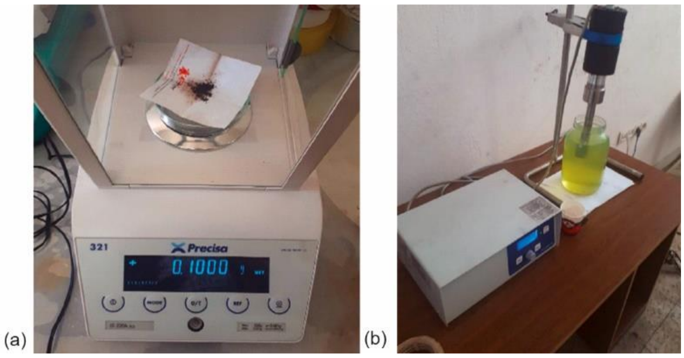

Figure 2. (a) Precision scales (Precisa 321) and (b) Ultrasonic Blender (Bandelin-UW3400)

Brake thermal efficiency

Figure 3 depicts brake thermal efficiency values [%] versus the engine load [%]. It has been observed that the efficiency of the engine increases with the increase of the load and the closest efficiency values to diesel fuel is in $ZnCO_3$-100 and $ZnFe_2O_4$-50 additive nanoparticles. The highest and lowest brake thermal efficiency values were obtained with 35.42% in D-$ZnFe_2O_4$-50 at 100% load and 29.51% in D-$ZnCO_3$-50 at 65% load, respectively. Generally, there has been little change in brake thermal efficiency with increasing load. The brake thermal efficiency of D-$ZnFe_2O_4$-50 has been tested to be higher than that of pure diesel. The brake thermal efficiency for D-$ZnCO_3$-100 were obtained quite close to pure diesel.

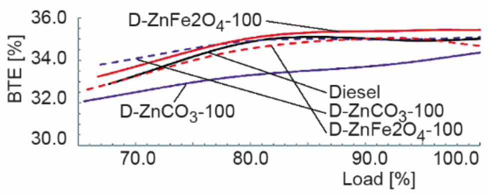

Figure 3. Brake thermal efficiency values *vs.* the engine load [%]

Cylinder pressure

Figure 4 shows the cylinder pressure for 250 Nm (a) and 380 Nm (b). Maximum cylinder pressure values for all mixtures have been obtained higher than diesel fuel at 250 Nm. The highest cylinder pressure values are in D-$ZnCO_3$-100 and D-$ZnFe_2O_4$-50. Maximum pressure points and values for D-$ZnCO_3$-100, D-$ZnFe_2O_4$-50, D-$ZnCO_3$-50, D-$ZnFe_2O_4$-100 and diesel fuels, 366 CA and 43.68 bar, 366 CA and 42.6 bar, 364 CA and 41.59 bar, 365 CA and 41.08 bar and 366 CA 40.11 bar, respectively. When examined together with efficiency, it can be said that the D-$ZnCO_3$-50 mixture, which has the lowest efficiency, consumes more fuel and obtains more pressure. Also, the maximum pressure point of D-$ZnCO_3$-50 fuel is 2 CA earlier than diesel fuel. This is one of the parameters that affect the brake thermal efficiency. It is seen in the fig. 4(a), all additives shorten the ignition delay time 380 Nm, fig. 4(b), is full load point, maximum pressure and CA points of all investigated fuel mixtures are very close to each other. When the efficiency values in fig. 3 are examined, it is seen that the efficiency values are close to each other at full loads. In full load condition, the changes are not obvious since it is the maximum amount of fuel in the cylinder.

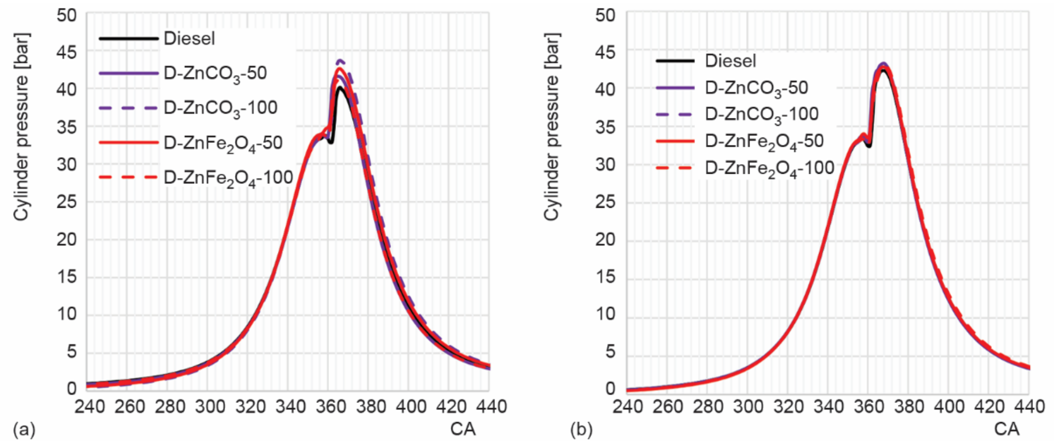

Figure 4. Cylinder pressure values to CA; (a) 250 Nm and (b) 380 Nm (full load)

Cylinder pressure

If the combustion process is not complete or if there is insufficient oxygen, some of the fuel may not be fully oxidized and can produce CO instead of CO_2. The CO is a toxic gas that can be harmful to human health and the environment, and it is a major component of vehicle exhaust emissions [45].

Figure 5(a) shows CO values *vs.* the engine load. Maximum CO values appear in D-$ZnCO_3$-50. The CO values also indicate poor combustion and an effect on its efficiency. The CO values of D-$ZnCO_3$-100, D-$ZnFe_2O_4$-50 and D-$ZnFe_2O_4$-100 are lower than the CO values of diesel fuel. The lowest Co values were obtained in D-$ZnFe_2O_4$-50. This is also the fuel mixture with the most efficiency.

Unburned hydrocarbons can be a problem in a number of different settings. In automobile engines, for example, incomplete combustion can result in the release of unburned hydrocarbons into the atmosphere, contributing to air pollution. Unburned hydrocarbons can also be a problem in industrial settings, such as refineries, where they may contribute to emissions of volatile organic compounds [46]. Figure 5(b) depicts unburned hydrocarbon values [$gkW^{-1}h^{-1}$] to engine load [%].

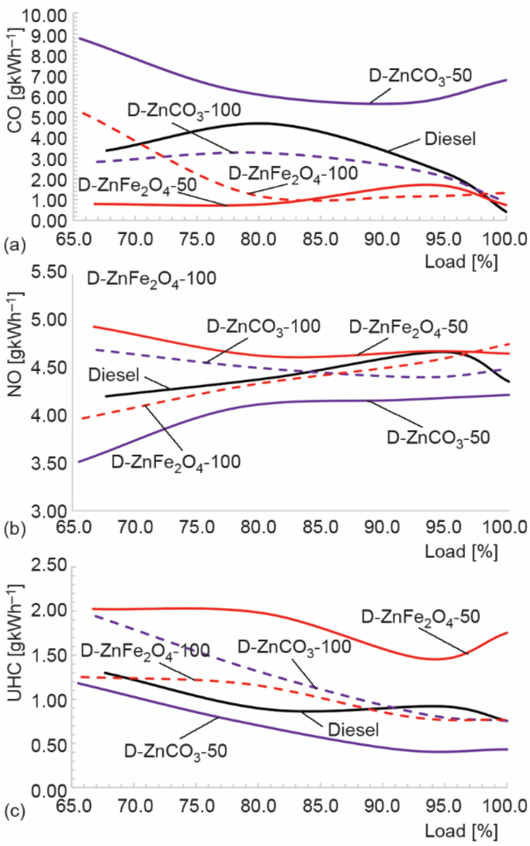

Figure 5. (a) The CO values [$gkW^{-1}h^{-1}$], (b) unburned hydrocarbon values, and (c) NO values to engine load [%]

Unburned hydrocarbon values have been illustrated in fig. 5(b). The unburned hydrocarbon values decrease with increasing load. Although the lowest efficiency was D-$ZnCO_3$-50 when examined with efficiency, the lowest value was obtained in D-$ZnCO_3$-50. However, the unburned hydrocarbon values are close to each other.

The NO_x refers to a group of pollutants that includes NO and NO_2. These pollutants are generated during the combustion of fuels at high temperatures, such as in internal combustion engines. The NO_x emissions are a significant contributor to air pollution, and can have adverse effects on human health and the environment [47]. In order to have high efficiency in internal combustion engines, good combustion, high temperature and pressure are required in the cylinder. High temperature pressure means an increase in NO values. Figure 5(c) shows NO values *vs.* the engine load. The maximum values have been obtained at D-$ZnFe_2O_4$-50 mixture. Also, in this mixture, the maximum efficiency values have been observed, fig. 3. The minimum values of NO have been measured in D-$ZnCO_3$-50. In this mixture, the minimum efficiency values has been stated.

Conclusion

In this study, $ZnCO_3$ and $ZnFe_2O_4$ nanoadditives were mixed with 50 ppm and 100 ppm diesel fuel with an ultrasonic mixer. The engine performance and emission values of the mixed fuels were investigated in a 11670 cc heavy-duty engine at 600 rpm at 250, 300, 350, and 380 (full load) load values. Following are the main findings.

- The highest efficiency values and the lowest efficiency values were obtained at D-$ZnFe_2O_4$-50 and D-$ZnCO_3$-50, respectively.
- In-cylinder pressure values of fuels with additives were higher than diesel fuel at 250 Nm (65% load). In-cylinder pressure values at full load were obtained close to each other in all fuels.
- The lowest CO values were measured in D-$ZnFe_2O_4$-50 fuel and the highest in D-$ZnCO_3$-50 fuel.
- The change in NO values have been measured the same as the brake thermal efficiency values.

Consequently, It is seen in the literature that mixtures with zinc components are limited. In this study, it is emphasized that $ZnCO_3$ and $ZnFe_2O_4$ nanoadditives can also be used as additives in diesel fuels. In further studies, it would be appropriate to add $ZnCO_3$ and $ZnFe_2O_4$ additives to biodiesel-diesel mixtures and make detailed analyzes.uthors are obliged to use System International for units (including non/SI units accepted for use with the SI system) for all physical parameters and their units.

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