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Correlation between Effects of Cerium Oxide Nanoparticles and Ferrofluid on the Performance and Emission Characteristics of a C.I. Engine

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ABSTRACT: *This report is related to find out correlation between performance and emission characteristics of a compression ignition engine while using cerium oxide nanoparticles and water-based ferrofluid as additive to diesel fuel. The cerium oxide acts as an oxygen donating catalyst and provides oxygen for the oxidation of CO or absorbs oxygen for the reduction of NOx. The activation energy of cerium oxide acts to burn off carbon deposits within the engine cylinder at the wall temperature and prevents the deposition of non-polar compounds on the cylinder wall results reduction in HC emissions. Adding ferrofluid to diesel fuel has a perceptible effect on engine performance, increasing the brake thermal efficiency relatively up to 12% and decreasing the brake- specific fuel consumption relatively up to 11% as compared to diesel fuel. Furthermore, from the analysis of engine exhaust, it was found that NOx emissions were lower than that of diesel fuel while the CO emissions increased.*

KEYWORDS: *Engine Performance, Emission Characteristics, Emission control, Ferrofluid, Fuel additives.*

I. Introduction

Diesel is essential for transport and heavy-duty engines. It contributes to the prosperity of the worldwide economy since it is widely used due to high combustion efficiency, reliability, adaptability and cost-effectiveness. However, pollutant emissions are a major drawback. Emissions from diesel engines seriously threaten the environment and are considered one of the major sources of air pollution. It was proved that these pollutants cause impacts in the ecological systems, lead to environmental problems, and carry carcinogenic components that significantly endanger the health of human beings. They can cause serious health problems, especially respiratory and cardiovascular problems. Increasing worldwide concern about combustion-related pollutants, such as particulate matter (PM), oxides of nitrogen (NOx), carbon monoxide (CO), total hydrocarbons (THC), acid rain, and photochemical smog and depletion of the ozone layer has led several countries to regulate emissions and give directives for implementation and compliance. It is commonly accepted that clean combustion of diesel engines can be fulfilled only if engine development is coupled with diesel fuel reformulation or additive introduction. In this way, methods to reduce PM and NOx emissions include high- pressure injection, turbo charging, and exhaust after treatments or the use of fuel additives, which is thought to be one of the most attractive solutions.

II. Requirement of Additives

Diesel oil is a fuel derived from petroleum and consists mainly of aliphatic hydrocarbons containing 8- 28 carbon atoms with boiling points in the range of 130-370 °C. It is a blend of fractions of hydrocarbons heavier than those of the hydrocarbons in gasoline and with a lower H/C mass ratio, which determines the high emission of carbon compounds per unit of energy delivered to the engine. A reduction in consumption and improvements in the quality of diesel oil have been the object of study by various specialists, motivated by growing demands in the transport and electric sectors. Several additives are added to perform specific functions. Additives reduce emissions; improve fluid stability over a wider range of conditions; improve the viscosity index, reducing the rate of viscosity change with temperature; and improve ignition by reducing its delay time, flash point, and so forth[1]. Diesel additives can be classified according to the purpose for which they are designed. Pre flame additives are designed to correct problems that occur prior to burning and include dispersants, pour point depressants, and emulsifiers, which act as cleaning agents. Flame additives are used to improve combustion efficiency in the combustion chamber, to increase cetane number, to reduce the formation of carbon deposits, to avoid oxidation reactions and contamination of fuel and filters clogging by rust, and to inhibit potential explosions caused by changes in static electricity. Post flame additives are designed to reduce carbon deposits in the engine, smoke, and emissions [1], [2].

III. Ferrofluid

Ferrofluids are colloidal suspensions of magnetic material in a liquid medium that respond to an external magnetic field. One of the most important features of ferrofluids is their stability, which means that particles in the fluid do not agglomerate and phase-separate even in the presence of strong magnetic fields [6]. The synthesis was based on reacting iron II ($FeCl_2$) and iron III ($FeCl_3$) ions in an aqueous ammonia solution to form magnetite, Fe_3O_4, as shown in the following equation:

$$FeCl_2 + 2FeCl_3 + 8NH_3 + 4H_2O \longrightarrow Fe_3O_4 + 8NH_4Cl$$

The cited procedure claims that those nanoparticle diameters are on the order of 10 nm. Furthermore, aqueous tetra-methyl-ammonium hydroxide ($(CH_3)_4NOH$) solution which was used as a surfactant can surround the magnetite particles with hydroxide anions and tetra-methyl-ammonium cations to create electrostatic interparticle repulsion in an aqueous environment [6], [9].

IV. Experimental Setup And Procedure

The use of cerium oxide nanoparticles in neat diesel has the tendency to settle down at the fuel tank. It is found that the blends subjected to high speed blending followed by ultrasonic bath stabilization improves the stability. The detailed procedure and experiment test facility is explained by Arul Mozhi Selvan *et al* [3], [4].

1. Engine chassis
2. Exhaust gas analyzing probe,
3. Exhaust gas analyzer,
4. Single cylinder VCR engine,
5. Load cell,
6. Dynamometer,
7. Tachometer,
8. Control unit,
9. Fuel burette,
10. Fuel container

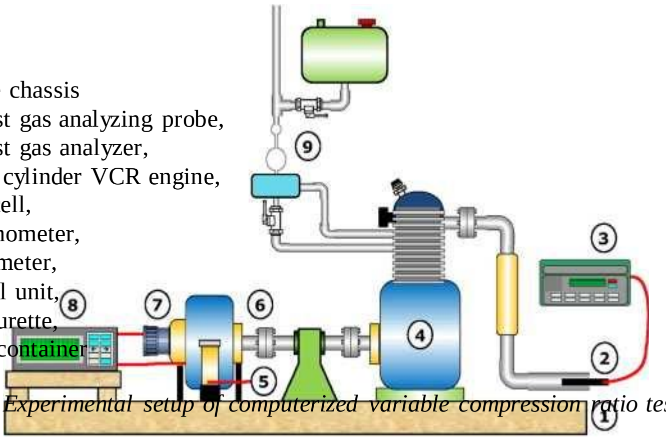

Figure-1 Experimental setup of computerized variable compression ratio test rig

The performance tests for the neat diesel with cerium oxide nanoparticles and ferrofluid as fuel-borne catalyst additives are carried out on a computerized single cylinder four stroke direct injection variable compression ratio engine. Figure-1 shows the schematic diagram of the experimental setup. The experimental setup consists of a variable compression ratio engine coupled to an eddy current dynamometer. A computerized data acquisition system is used to collect, store and analyze the data during the engine testing. A piezoelectric pressure transducer and a crank angle encoder are used to measure the in-cylinder gas pressure and the corresponding crank angle. The load applied on the engine is measured by the load cell connected to the eddy current dynamometer. A burette with two infrared optical sensors measures the fuel flow rate, an air flow sensor measures the inlet air flow rate, and thermocouples measure the inlet air and exhaust gas temperatures. Analyzer is used to measure the exhaust gas constituents such as CO, HC, NO and the smoke is measured using the smoke meter. All the experiments are conducted at the compression ratio of 19, with respect to engine load at engine speed 2200 rpm, and the results are recorded under steady state conditions [3], [4], [6].

V. Correlation between Effects of Cerium Oxide Nanoparticles and Ferro-fluid on the Performance and Emission Characteristics of a C.I. Engine

The following section illustrates the results obtained from the performance and emission characteristics of the CI engine.

5.1. Engine Performance

The brake-specific fuel consumption (BSFC) and the brake thermal efficiency (BTE) can be calculated by the engine torque, the engine speed, and the mass consumption rate of the fuel.

5.1.1. Brake-Specific Fuel Consumption (BSFC)

The variation of brake specific fuel consumption (BSFC) with brake mean effective pressure (BMEP) is shown in Figure-2.

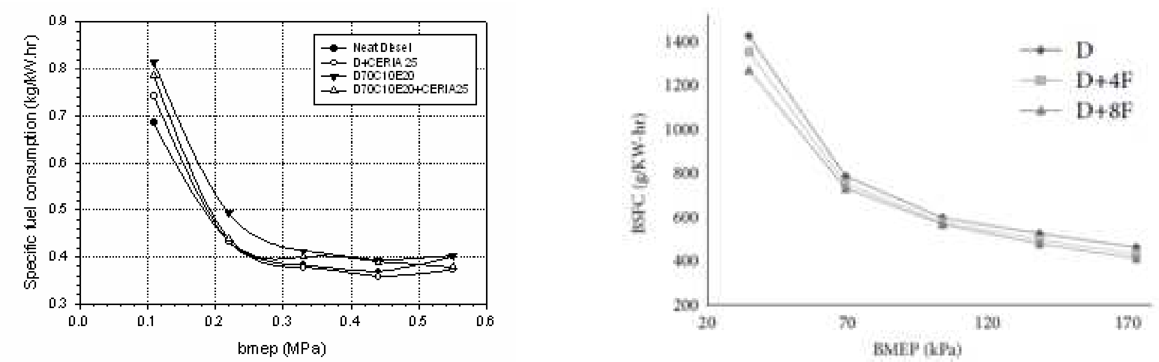

Figure-2 Variation of BSFC with BMEP with respect to engine load at 2200 rpm

The brake specific fuel consumption (BSFC) decreases with an increase in the engine load for the diesel cerium oxide blends than neat diesel at all the BMEP. The lowest BSFC is observed as 0.3586kg/kW.hr for the D+CERIA25 blend whereas it is 0.3931kg.kW.hr for neat diesel at the brake mean effective pressure (BMEP) of 0.44Mpa. This phenomenon is due to the result of cerium oxide addition which promotes combustion hence less quantity of fuel is consumed to maintain the engine speed constant. This is obvious from the fact that the increase in fuel required to operate the engine is less than the increase in brake power at higher loads [3], [4].

Adding a ferrofluid to diesel fuel will decrease the BSFC. Adding 0.4% ferrofluid to diesel fuel decreased the BSFC relatively by 3.23–6.45%, and adding 0.8% ferrofluid to diesel fuel decreased the BSFC relatively by 5.06–10.85%. The decrease in BSFC can be due to the positive effects of nanoparticles on physical properties of fuel and also reduction of the ignition delay time, which lead to more complete combustion. In addition, it can be due to effects of nanoparticles on fuel propagation in the combustion chamber. On the other hand, nanoparticles added to diesel fuel increase the mixture momentum and, consequently, the penetration depth in the cylinder. As a result, combustion is improved. In addition, the higher viscosity of the emulsified fuel than that of the base fuel and the presence of water promote a finer, cloud-like atomization of the emulsified mixture during injection, resulting in improving combustion efficiency significantly. It has been claimed that the water in the emulsified fuel improves the combustion process owing to the simultaneous additional braking of the droplets, to the increase in evaporation surface of the droplets and to better mixing of the burning fuel in air [6].

5.1.2. Brake Thermal Efficiency (BTE)

The variation of Brake Thermal Efficiency (BTE) with brake mean effective pressure (BMEP) is shown in Figure-3. For all fuels, the BTE increases with the increase in engine load for all different fuels.

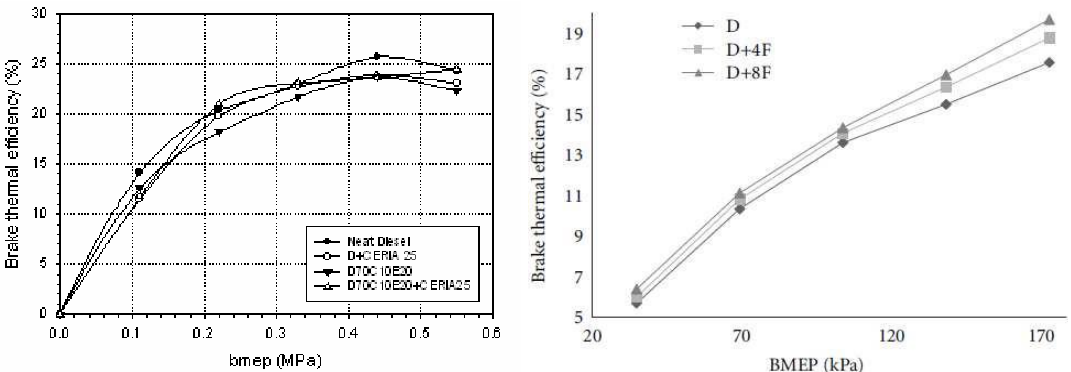

Figure-3 Variation of BTE with BMEP with respect to engine load at 2200 rpm

The brake thermal efficiency of the neat diesel is higher among all the fuel blends. The brake thermal efficiency of the diesel ethanol blends is lower due to lower calorific value of the blend. However a small improvement in brake thermal efficiency is observed with the addition of cerium oxide with diesel ethanol blends. The highest brake thermal efficiency is observed as 25.66% for neat diesel whereas it is 23.63% for the

D+CERIA25 blend under the same BMEP of 0.44MPa [3], [4].

BTE is dependent on BSFC, and thus the BTE of D+4F and D+8F similarly improved compared to diesel fuel for the same reasons. Adding 0.4% ferrofluid to diesel fuel increased the BTE by 3.33–6.89% relatively and adding 0.8% ferrofluid to diesel fuel increased the BTE by 5.33–12.17% relatively. Adding ferrofluid to diesel fuel has a perceptible effect on engine performance [6].

5.2. Emission Characteristics

5.2.1. Carbon Monoxide (CO)

The variation of carbon monoxide (CO) with BMEP with respect to engine load at 2200 rpm is Shown in Figure-4 for different fuels. It is observed that the CO emission decreased with an increase in engine speed for all fuels.

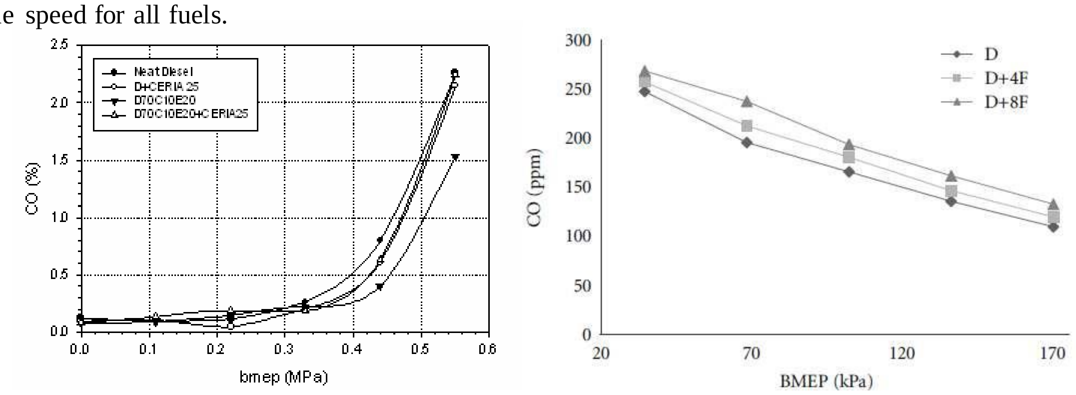

Figure-4 Variation of CO with BMEP with respect to engine load at 2200 rpm

The CO emission is marginal up to the BMEP of 0.44 MPa and then increases rapidly with higher load. The addition of cerium oxide further decreases the CO emission when comparing with neat diesel [3], [4]. An observation of Figure 4 shows that adding ferrofluid to diesel fuel increases CO emissions. D+4F increased CO emission by 10 to 17 ppm, and adding 0.8% ferrofluid to diesel fuel increased CO emissions by 21 to 42 ppm. CO emission greatly depends on the air-to-fuel ratio relative to stoichiometric proportions. Generally, CI engines operate with lean mixture, and hence CO emissions would be low. As mentioned before, nanoparticles may have affected fuel propagation in the combustion chamber. Hence, the increase in CO emission may be due to operation of the engine using D+4F and D+8F in different situation compared to diesel fuel [6].

5.2.2. Oxides of Nitrogen (NO*x*)

The variation of nitrogen oxides (NO*x*) emissions with BMEP with respect to engine load at 2200 rpm for different fuels is shown in Figure-5. NO*x* emissions increase with engine load for all fuels.

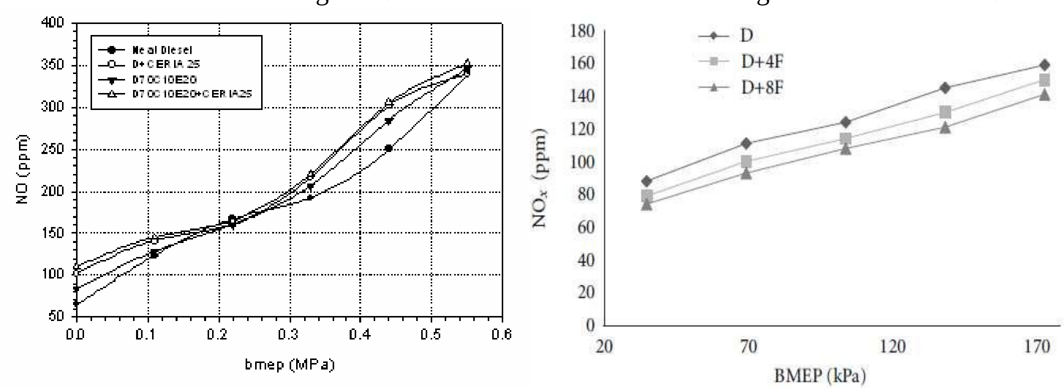

Figure-5 Variation of NOx with BMEP with respect to engine load at 2200 rpm

The NO*x* emission is lower for the neat diesel when comparing to all the fuel blends containing Cerium oxide. The effect of oxygenated additives enhances combustion and the longer ignition delay results in faster premixed combustion are the causes for higher combustion temperature and the subsequent higher NO*x* emission. The least NO*x* is observed as 250ppm for neat diesel at the BMEP of 0.44 MPa [3], [4].

Compared with diesel fuel, D+4F and D+8F decreased NO*x* emissions at all loads. Adding 0.4% ferrofluid to diesel fuel decreased NO*x* emissions by 9 to 15 ppm, and adding 0.8% ferrofluid to diesel fuel decreased NO*x* emissions by 14 to 24ppm. Many factors contribute to the formation of NO*x emissions*. According to the Zeldovich mechanism, the formation of NO*x* is dependent on oxygen concentration, residence time, and temperature. This reduction may be due to the latent heat of evaporation of water, the high thermal capacity of water, and also nanoparticles, which can reduce the temperature in the combustion chamber and consequently

Reduce NO*x* emissions [6].

VI. Conclusion

Diesel emissions from mobile sources have raised health and welfare concerns, but a number of technologies exist that can greatly reduce emissions from diesel-powered vehicles. One of the methods to vary the physicochemical properties and combustion characteristics of a hydrocarbon fuel is the use of additives, which are found to be especially effective in nanoparticle form, due to the enhancement of the surface area to volume ratio.

The addition of cerium oxide as oxygenated additives promotes complete combustion is the cause for the hydrocarbon emission reduction. The effect of oxygenated additives enhances combustion results in faster premixed combustion is the cause for higher combustion temperature and the subsequent higher NOx emission. The CO emission shows marginal decrease and then increases with higher ppm of cerium oxide.

Adding water-based ferrofluid to diesel fuel of 0, 0.4, and 0.8 ferrofluid/diesel ratios by volume at 2200 rpm not only improves engine performance (increasing BTE and decreasing BSFC) but also reduces NO*x* emissions. However, CO emissions increase. Furthermore, the results showed that increasing ferrofluid concentration will magnify the results.

If both cerium oxide nanoparticles & ferrofluid are added to the neat diesel then we can combine favorable effects of both additives in order improve performance & emission characteristics of CI engines.

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