The Effect of Compression Ratio on Pollutant Emission of a Diesel Engine Fuelled with Nano Diesel

Abdulkhodor Kathum Nassie*,1, Haroun A. K. Shahad2

Department of Mechanical Engineering, Babylon University, Babylon-Iraq

*Corresponding Author E-mail: alhaji84@yahoo.com

Abstract

This study aims to examine the impact of compression ratio (CR) on the pollutants of a compression ignition engine (CIE) fuelled with Nano-diesel. Nano-particles of Al2O3 and TiO2 are used as additives to diesel fuel with particle size less than 45 nm. The impact is tested for 25, 50, 100 and 150 ppm doses. Tests are performed at different loads and a speed of 1500 rpm. Three CR are used namely 13.5, 15.5 and 17.5. Results illustrated the effect of CR on the emissions of CO, CO2, NOx, smoke opacity and UHC. Results showed that CO concentration rises with increased CR for Al2O3. It is increased by 2.5, 4.9 and 15.3% for the three ratios at 100 ppm and 25% load while at full load there is no much effect as a result of high combustion temperature. Negligible effect is noticed for TiO2. The concentration of CO rises with increasing CR at all doses but it is very clear with 150 ppm and 25% load 3.7, 4.1 and 4.8% for Al2O3. The effect of TiO2 is higher than that of Al2O3. The results also, show that NOx concentration is increased and becomes 604. 651 and 698 ppm for 13.5, 15.5 and 17.5 respectively for Al2O3 at 25 ppm and 25% load. The impact of Al2O3 is more noticeable than that of TiO2. The smoke opacity is slightly affected by CR for Al2O3 and TiO2 at all doses and 25% load. UHC decreases slightly from 79, 75 and 71 ppm for CR of 13.5, 15.5 and 17.5 respectively for Al2O3 at 25 ppm and 25% load. UHC decreases from 68, 65 and 61 ppm for CR 13.5, 15.5 and 17 respectively for TiO2 at 25 ppm and 25% load.

Keywords: -CR, Nano diesel, Nano-particle, Exhaust emission.

1. Introduction

Air pollution due to combustion emissions is a problem of intense concern because of exposure of large number of people to it. However vehicular emission is responsible for higher level of air pollutants such as NOx, CO, and other organic and inorganic pollutants including metal traces and their adverse effects on human and environmental Barman.et.al[1]. Saree et al.[2] was able to reduce the pollutants emission concentration and fuel consumption in a diesel engine by using silver nanoparticles with minor engine modification. They attributed that to the improvement in heat transfer to fuel and longer fuel spray penetration caused by presence of Nano particles.

An experimental study was carried out by Lenin.et.al[3] to analyze the effect of nanoparticles on operating characteristic of single – cylinder, air cooled and directed injection (DI) diesel engine. They used magnesium oxide and copper oxide as an additive metal. Maximum UHC was noticed at low load with small decrease at full load. The manganese additive showed a decrease in CO and NOx emission by 37% and 4% respectively. Fang.et.al[4] studied impact of nanoparticles on the palm oil biodiesel characteristics. They used TiO2 nanoparticles with dosing 1% and 5% palm oil. The emission of CO, UHC, NOx and soot were all decreased. Rakhit.et.al[5] carried out an experimental work to study the effect of addition of energetic nanoparticles such as aluminum, iron and boron to diesel fuel on combustion process in a CIE. They found that CO concentration was reduced by 25-40% when additives are used.

UHC concentration was also reduced by 8% and 4% for engine fueled with energetic Nano-fuel when compared with engine fueled with neat diesel fuel. Karthikeyan.et.al[6] tested the effect of zinc oxide nanoparticle (ZnO) on biodiesel (Pomolton stearin wax) combustion characteristics. Their tests were conducted on a single cylinder, air cooled, and stationary DI diesel engine at fixed speed 1500 rpm. The UHC, CO and smoke concentrations were decreased. Not much effect on NOx concentration was observed. Ozgurel.et.al[7] performed experimental teston the effect of adding Nanoparticles to the diesel fuel on the emission of NOx, 4-cylinder, 4-stroke, naturally aspirated and water-cooled CIE was used in their study. Nine nanoparticles such as MgO, Al2O3, TiO2, ZnO, SiO2, Fe3O4, NiO, NiFe2O4 and ZnO0.5NiO0.5Fe2O4 were used. They found that addition of all nanoparticles expect Al2O3 led to a reduction in the NOx emission. The maximum reduction was found at 100 ppm dosing of MgO.

Prabakaran B. [8] studied experimentally the effect of ZnO Nano-particles on CIE pollutants concentration and performance. He found that there was a reduction in NOx and smoke concentrations.

Gnanasik.et.al[9] tested experimentally the impact of Al2O3 NANO-particles addition to methyl ester of Neem oil fuel on combustion process in a direct injection CIE. Three dozes of Al2O3 nanoparticles were used, namely, 100 ppm, 200 ppm and 300 ppm. The size of nanoparticles was (1 to 110 nm). The performance and emission were studied on a 4-stroke, stationary, water cooled CIE a speed of 1500 rpm and 3.5 kW power. The results showed that nanoparticles reduced NOx by 3.12%, 7.15% and 4.97% for the three doses respectively.

Jeryajkumar.et.al [10] studied experimentally the impact of nanoparticles additions to biodiesel on engine emissions.
They used (Co3O4) and (TiO2) as nanoparticles. The test were performed ona 4-stroke, water cooled CIE. It was found that (CO) concentration was decreased by 30% and 25% for (Co3O4) and the (TiO2) respectively. UHC was dropped by 80%, 70% for (Co3O4) and (TiO2) respectively.

Gumus et al. [11] investigated the impact of Al2O3 and CuO on performance and pollutants concentration of a diesel engine. They found that there was a reduction in fuel consumption and a reduction in pollutants emission.

Nasir [12] analyzed experimentally the effect of adding Al2O3 and TiO2 nanoparticles to diesel fuel on combustion process in a single cylinder CIE. The results indicated that emissions like carbon monoxide concentration was reduced by 40% and 46% while CO2 was increased by 6.7% and 8% for Al2O3 and TiO2 respectively for the lowest dose at three quarters load. The nitrogen oxide NOx was increased with Al2O3 from 1013 ppm to 1055 ppm, while it was decreased with TiO2 from 1013 ppm to 906 ppm at full load and 25 ppm. The smoke opacity was decreased by 28% and 25% for TiO2 and Al2O3 respectively. The UHC was increased with Al2O3 and decreased with TiO2 at full load and lowest dose.

2. Experimental Set up

A series of tests are carried out to investigate the impact of nanoparticles addition on combustion emission of a CIE. The engine specifications can be found in ref [13]. Fig (1) illustrates the experimental facility set up. The pressure history diagram, the engine RPM and temperature of exhaust gases recorded.

3. Measurement Instrumentation

The exhaust Gas analyzer type 953254 has been used for measuring CO, UHC, and CO2 in engine exhaust by the principle of non-dividing infrared absorption and for measuring NOx and O2 by the principle of electrochemical cell. A smoke meter BOSCH model MED 001 is used to measure, display and print out smoke concentration in the exhaust gases [14].

4. Nano-diesel Preparation

The chemical formula of fuel used is(C12H22). The related properties fuel and Nano particles are shown in table (1). The nanoparticles have a particle diameter less than 45 nm. The used doses are 25, 50, 100 and 150 ppm. The required particles quantity for each test is calculated using the following formula(1) [15].

\[
\phi = \frac{\rho_f}{m_f + \frac{\rho_j}{m_j}}
\]

(1)

Table (2) shows the required quantity of particles for each test.

| Substance | Density (kg/m^3) | Dynamic viscosity*10^4 (kg/m.s) | Specific heat(J/kg.K) | Thermal conductivity(W/m.°C) |
|-----------|-----------------|---------------------------------|-----------------------|------------------------------|
| Al2O3     | 3970            | ------                          | 765                   | 40                           |
| TiO2      | 4230            | ------                          | 710                   | 9                            |
| Diesel    | 844.3           | 2.778                           |                        |                              |

Each quantity of nanoparticles is mixed with (5 L) neat diesel and stirred for one hour by a stirrer and then for six hours in an ultrasonic cleaner type (JTS-1018) to ensure the through mixing and prevent aggregation [12].

| Volume ratio (ppm) | Quantity of particles (kg) (Al2O3) | quantity of particles (kg) (TiO2) |
|---------------------|------------------------------------|----------------------------------|
| 25      | 0.0025 | 0.4963x10^-5 | 0.529x10^-5            |
| 50      | 0.005  | 0.993x10^-5  | 1.058x10^-5            |
| 100     | 0.01   | 1.986x10^-5  | 2.116x10^-5            |
| 150     | 0.015  | 2.979x10^-5  | 3.174x10^-5            |

5. Results and Discussions

For easy presentation and discussions, the results are divided into sub-sections as below.

5.1. Carbon Monoxide (CO)

Fig (2) shows that the concentration of CO increases with the increase of CR. It is increased by (2.5%, 4.9% and 15.3%) for (13.5, 15.5 and 17.5) respectively for DF+Al2O3 at 100 ppm and 25% load because of lack of oxygen and incomplete combustion, while fig (3) shows that there is no much effect for CR at full load because of the high temperature. Fig (4) shows that no much change in CO concentration with the increasing of CR with DF+TiO2 because of a good mixing and complete combustion at 150 ppm and 25% load. Fig (5) shows the same trend at full load.
5.2. Carbon Dioxide (CO₂)

Fig (6) shows that CO₂ increases with the increasing of CR for all dozes of Al₂O₃ for example with 150ppm and 25% load the concentration are 3.7%, 4.1% and 4.8% for 13.5, 15.5 and 17.5 respectively. Fig(7) shows that CO₂ is increased by 5.7, 6.8 and 7.8 for (13.5, 15.5 and 17.5) respectively for DF+Al₂O₃ at 150ppm and full load. This is due to complete combustion which generates high temperatures. Fig (8) shows that CO₂ increases with the increasing of CR with all dozes of DF+TiO₂. At 150ppm and 25% load it is 3.5%, 3.7% and 4.5% for 13.5, 15.5 and 17.5 respectively while it is increased by 6.3%, 7.5% and 8.7% for 13.5, 15.5 and 17.5 respectively for DF+TiO₂ at 150ppm at full load, as shown in fig (9).

5.3. Nitrogen Oxides (NOₓ)

Fig (10) shows that NOₓ increases as 604, 651 and 698 ppm for CR of 13.5, 15.5 and 17.5 respectively for DF+Al₂O₃ at 25ppm and 25% load. This is due to the enhancement in temperature as the CR increases. Similar trend is noticed at full load as illustrated in fig (11). It is noticed that the NOₓ concentration rises with increasing CR for DF+TiO₂ as in figs (12 and 13). However, it is indicated that the effect of Al₂O₃ is more noticeable than that of TiO₂.

5.4. Smoke Opacity

Figs (14, 15, 16, 17) show that both Nano-particles have large impact on reducing smoke opacity. However, there is negligible effect of CR on smoke opacity for both DF+Al₂O₃ and DF+TiO₂ at all loads because both types improve mixing process of air and fuel which improves combustion efficiency.

5.5. Unburnt Hydrocarbon (UHC)

Figs (18 and 19) shows small decrease in UHC concentration as the CR increases for DF+Al₂O₃ at part load and full load conditions. Same trends are noticed for DF+TiO₂ at both part and full loads conditions as shown in figs (20 and 21).

6. Conclusions

1. CO emission increases with the increasing of CR with Al₂O₃ but little effect is noticed with TiO₂.
2. CO₂ increases with the increasing of compression ratio for both types of nanoparticles.
3. NO₂ emission increases with the increasing of compression ratio.
4. Effect of CR is negligible on smoke opacity for both types of Nano-particles.
5. UHC concentration decreases slightly with the increasing of CR for both types of Nano-particles.

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Fig. 1: Schematic Diagram of 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. 2: Variation of CO with the compression ratio at Part Load Conditions

Fig. 3: Variation of CO with the compression ratio at Full Load Conditions

Fig. 4: Variation of CO with the compression ratio at Part Load Conditions
Fig. 5: Variation of CO with the compression ratio at Full Load Conditions

Fig. 6: Variation of CO$_2$ with the compression ratio at Part Load Conditions

Fig. 7: Variation of CO$_2$ with the compression ratio at Full Load Conditions

Fig. 8: Variation of CO$_2$ with the compression ratio at Part Load Conditions
Fig. 9: Variation of CO$_2$ with the compression ratio at Full Load Conditions

Fig. 10: Variation of NO$_x$ with the compression ratio at Part Load Conditions

Fig. 11: Variation of NO$_x$ with the compression ratio at Full Load Conditions

Fig. 12: Variation of NO$_x$ with the compression ratio at Part Load Conditions
Fig. 13: Variation of NO\textsubscript{x} with the compression ratio at Full Load Conditions

Fig. 14: Variation of smoke opacity with the compression ratio at Part Load

Fig. 15: Variation of smoke opacity with the compression ratio at Full Load Conditions

Fig. 16: Variation of smoke opacity with the compression ratio at Part Load Conditions
Fig. 17: Variation of smoke opacity with the compression ratio at Part Load Conditions

Fig. 18: Variation of UHC with the compression ratio at Part Load Conditions

Fig. 19: Variation of UHC with the compression ratio at Full Load Conditions

Fig. 20: Variation of UHC with the compression ratio at Part Load Conditions
Fig. 21: Variation of UHC with the compression ratio at Full Load Conditions