Research Article

International Journal of Petrochemistry & Natural Gas

Methodology To Reduce Diesel Engine Pollutant Emissions

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Submitted: 04 Feb 2021; **Accepted**: 14 Feb 2022; **Published**: 26 Feb 2022

Citation: *Ahmad Saylam. (2022). Methodology To Reduce Diesel Engine Pollutant Emissions. Int J Petro Chem Natur Gas, 1(1):04-08.*

Abstract

Due to the climate change and health issues, more restrictive legislations concerning the pollutant emissions of diesel engines take place in the worldwide. A novel approach to reduce the pollutant emissions of CO, NOx and unburned hydrocarbons (HC) in diesel engines is thus proposed. It's based on fuelling diesel engines by blends of selective additives mixture and the conventional commercial diesel fuel. In order to prove the feasibility of such an approach, blends of additives mixture and a diesel fuel surrogate of n-dodecane and m-xylene are numerically investigated using a homogeneous multi-zones reactor approach and detailed chemistries with covering a wide blending range of air–fuel ratio (AFR) 9.8 – 29.4 and engine speed 1000 - 2000 rpm. The employed mixture of additives reduces considerably the emissions of CO and HC, up to 60%, especially for the rich conditions AFR = 9.8, with generally very slight reduction to NOx emission and decease to the engine produced power for all the blending ratios. The reduction of NOx emission is thus reachable by the accessibility to operate the engine at low compression ratio blending the additives mixture. The proposed approach requests indeed to be validated experimentally and be coupled with other emissions reduction technologies.

Keywords: Diesel Engine, Emissions, Additives, Exhaust Gas Recirculation, Multi-Zones Model

Introduction

Diesel engines have extensive usage compared to gasoline engines on account of their low-operating costs, energy efficiency, high durability, and reliability. However, diesel exhaust gas contains higher amount of pollutant emissions such as CO, NOx, unburned hydrocarbons (HC) and particulate matter (PM) that are responsible of several environmental and health problems [1, 2]. The so-called exhaust gas recirculation (EGR) and that of selective catalyst are the most focused technologies to substantially reduce NOx emission in diesel engines. To reduce the amount of HC and CO, the so-called diesel oxidation catalyst (DOC) is often applied [3-8]. As well, the diesel particulate filter (DPF) approach is used to reduce the mass and number of solid particles in the exhaust gas [9]. Nevertheless, the effects of additives on engine performance and emissions have been widely explored by numerous authors. Yanfeng et al. observed a reduction in the engine emissions of HC and CO and a little effect on NOx emissions when 2-methoxyethyl acetate is added to diesel fuel[10]. Similar behaviour obtained by Frusteri et al. using 1,1-diethoxyethane as additive [11]. Adding ethanol to diesel fuel reduces significantly the emissions of HC and CO and somewhat the NOx and CO2 emissions [12]. The effects of exhaust gas recirculation (EGR) and the addition of an oxygenated fuel of 20 wt % monoglyme and 80 wt% diglyme on combustion and emissions of diesel engine were studied experimentally by Song et al. [13]. The combination of flame temperature diminution and the suppression of soot precursors, attained by raising the EGR ratio and oxygen addition, contribute to both NOx and soot reduction with slight reduction in HC and CO emissions. The influence of EGR and the addition of 3-pentanone and methyl anon to diesel fuels on the performance and emission of a diesel engine was experimentally studied by Sundar Raj et al. [14]. Adding these oxygenated hydrocarbons reduces the production of soot precursors but it increases effectively the NOx emissions. Nonetheless, the EGR causes a simultaneously sharp reduction in NOx and smoke. The study of n-pentanol/diesel blends, 10%, 20%, 30% and 45% (by volume) and EGR ratio effects on the performance and emissions of a constant speed diesel engine has been effectuated by Rajesh kumar et al. [15]. Using these blends and the increasing of EGR ratio decrease the NOx emissions. All blends showed increases in HC and CO emissions when compared to diesel fuel under EGR conditions. Therefore, the focus of this modeling study is also on exploring the efficiency of fuelling diesel engines by blends of diesel fuel and here an innovative mixture of accessible additives to reduce their emissions of CO, NOx and HC.

Simulation Conditions and Approaches

In real combustion systems temperature stratification exists, which leads to significantly more drawn-out heat release events than are observed in single-zone model, as well as the problem of non-homogenous mixing of fuel/air in cylinder, which make the predicting of ignition and emissions formation using homogeneous single-zone model non-accurate. Therefore, the numerical simulation of a two-stroke diesel engine was performed using a homogeneous multi-zones reactor covering the range of Air–Fuel Ratio AFR= 9.8 – 29.4 and implementing detailed elementary reaction mechanisms and heat transfer to the cylinder walls. In this work, the engine produced power (PW) and emissions of a two-stroke Homogeneous Charge Compression Ignition (HCCI) diesel engine as a multi-zones reactor were predicted using the Ansys Chemkin-Pro 19.0 software [16]. The homogeneous single-zone model simulation to study the effects of EGR on PW and emissions of a diesel-type internal combustion engine were effectuated using an adapted python script form the software package CANTERA [17]. The heat transfer to the cylinder walls was estimated by Newton's law of cooling, Woschni's correlation and the CANTERA's default parameters [18].

A mixture of 77% of n-dodecane and 23% m-xylene by volume is investigated as a Diesel Fuel Surrogate (DFS) and the simulations are effectuated using the detailed kinetic mechanism of Lawrence Livermore National Laboratory for the combustion of DFS in combination with the detailed mechanism of Zhang et al. for the prediction of NOx emissions [19-20].

The following table presents the basic parameters of the engine simulation:

Displacement (cm^3)	332
Bore / stroke (mm)	65 / 100
Con. rod length (mm)	200
Comp. ratio	15
Engine speed (rpm)	1000 - 2000
Intake temperature (K)	323
Intake pressure (bar)	1
Fuel ratio (AFR)	9.8

Results and Discussion

The intake temperature and pressure (T_{in}, p_{in}) of the adopted fuels/air mixture for this study were 323 K and 1 bar, respectively. The engine speed (*Es*), the compression ratio (*Cr*) and the Air–Fuel Ratios (AFR) were 1000 rpm, 15 and 9.8, 14.71 and 29.4, respectively, which correspond to equivalence ratios of 1.5, 1 and 0.5, respectively. Figure 1 shows the variations of in-cylinder pressure crank angle histories depending on the injected AFR of DFS. The simulated zonal temperature distribution of DFS for AFR = 14.71 is demonstrated in figure 2. Figures 3-5 present the exhaust concentration of CO, NOx and HC in function of Volume Percent of Additives mixture (VPA) to DFS. The mixture of additives reduces the emissions of CO and HC especially for the rich conditions of AFR = 9.8 with generally very slight reduction to NOx emissions for all the mixing ratios. Figure 6 shows a comparison of PW expressed in torque (N.m) in function of VPA. The PW decreases in the range of 4% to 11% depending on the employed blending ratio. Figure 7 presents the variations of Relative Performance percentage to the original case values of using the pure DFS, RPDF (%), in function of VPA and for wide range of engine speed 1000-2000 rpm. It demonstrates such promising reduction of CO emission, up to 60 %, which must be also to HC emission with modest performance declining in term of NOx emission and produced engine power.

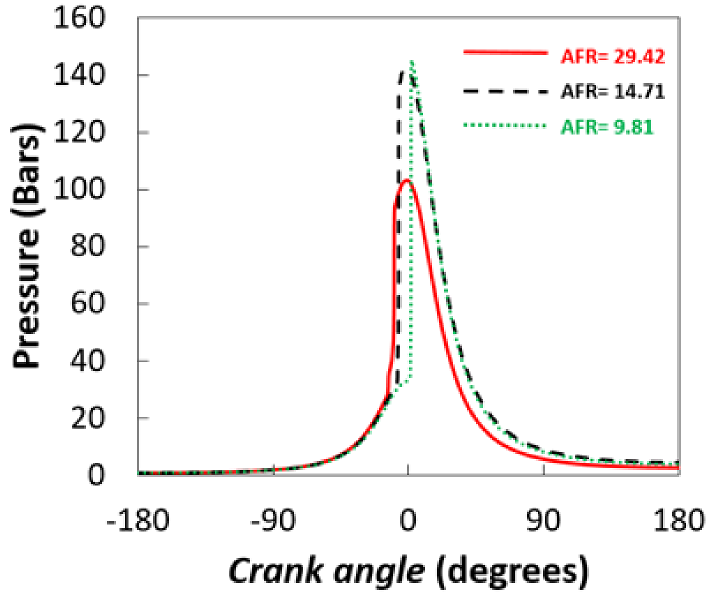

Figure 1: In-cylinder pressure crank angle histories in function of AFR at *Es* = 1000 rpm, *Cr* = 15, T_{in} = 323 K and p_{in} = 1 bar.

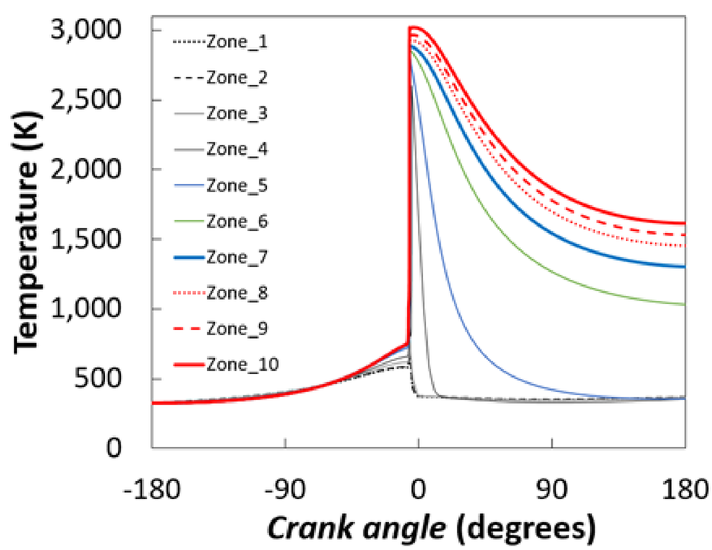

Figure 2: Zonal temperature distribution in function of crank angle for AFR= 14.71, *Es* = 1000 rpm, *Cr* = 15, T_{in} = 323 K and p_{in} = 1 bar.

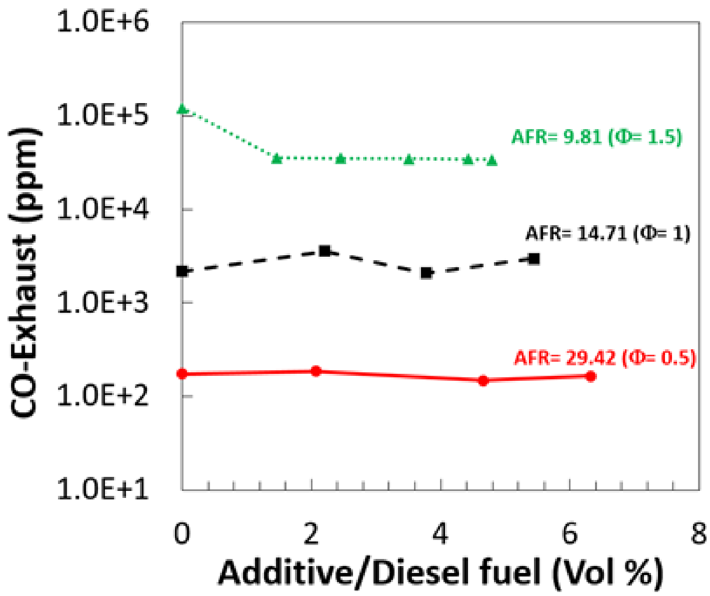

Figure 3: Exhaust concentration of CO in function of VPA at *Es* = 1000 rpm, *Cr* = 15, T_{in} = 323 K and p_{in} = 1 bar.

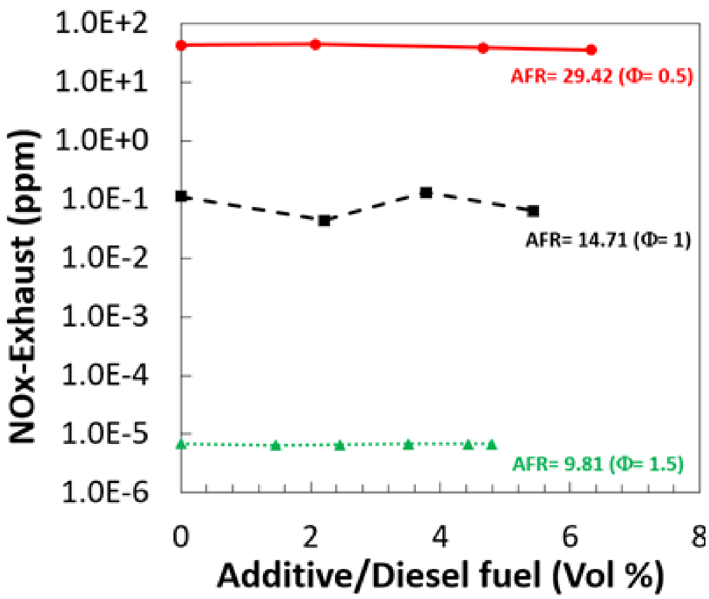

Figure 4: Exhaust concentration of NOx in function of VPA at *Es* = 1000 rpm, *Cr* = 15, T_{in} = 323 K and p_{in}= 1 bar.

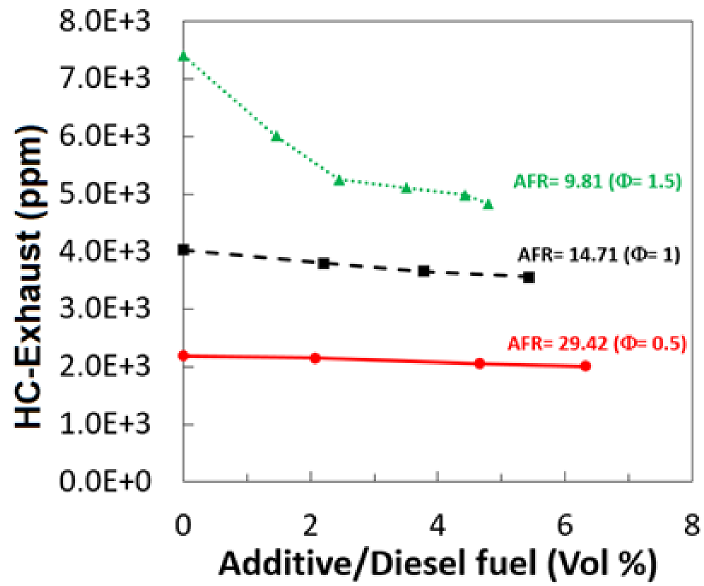

Figure 5: Exhaust concentration of HC in function of VPA at *Es* = 1000 rpm, *Cr* = 15, T_{in} = 323 K and p_{in}= 1 bar.

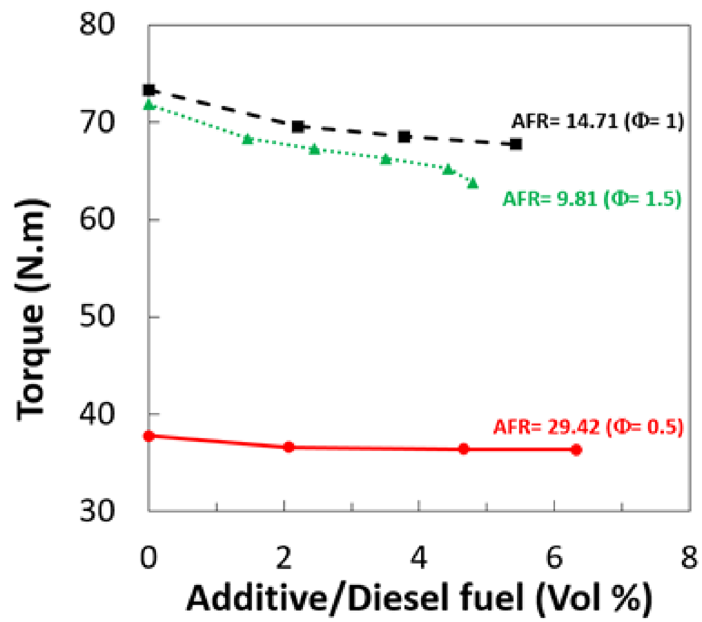

Figure 6: PW in Torque (N.m) in function of VPA at *Es* = 1000 rpm, *Cr* = 15, T_{in} = 323 K and p_{in} = 1 bar.

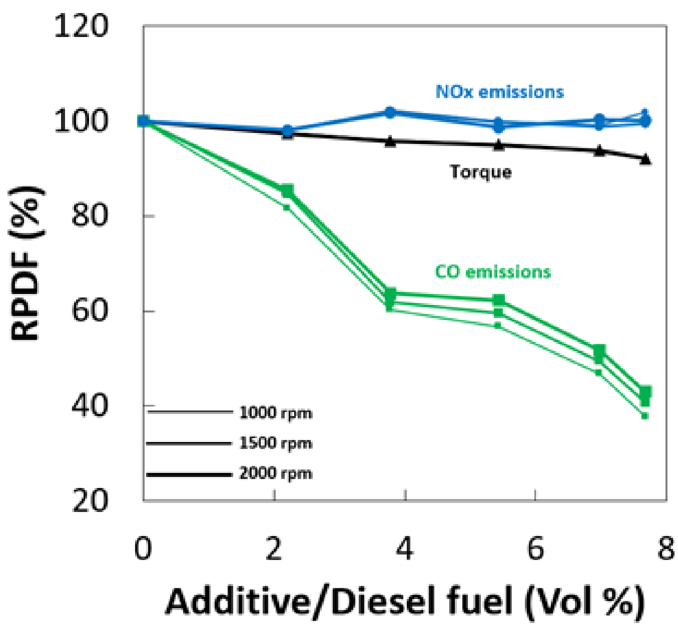

Figure 7: Relative performance percentage to using pure DFS in function of VPA for AFR = 14.71, *Es* = 1000 - 2000 rpm, *Cr* = 15, T_{in} = 323 K and p_{in} = 1 bar.

Conclusion

The modeling investigation results of the proposed methodology to reduce, up to 60%, the CO and unburned hydrocarbons (HC) and NOx pollutant emissions of diesel engines is promising with keeping in mind that its application is relatively simple, low-cost and could be effectively coupled with the other emissions reduction approaches as those of exhaust gas recirculation (EGR) [3, 4], selective catalyst [5, 6], diesel oxidation catalyst (DOC) [7, 8] and diesel particulate filter (DPF) [9] to achieve better and wider performance in term of emissions reduction of CO, NOx, HC and particulate matter (PM). The taking into consideration the exhaust gas recirculation ratios of positive effects on NOx emission reduction is one reason to get practically more boosting behaviour regarding this objective. Correspondingly, the reduction of NOx emission, reachable here by the accessibility to operate the engine at lower compression ratios regarding those using the pure diesel fuel (without the additives mixture), could be the subject of a perspective work. These modeling results necessity indeed to be validated experimentally. The validation process can offer other dimensions in the fields of emissions reduction and development of diesel engines

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