Experimental Analysis of the effect of very early pilot injection on pollutant formation for a PCCI Diesel engine

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In the present work, the influence of a very early pilot injection on pollutant formation was investigated in a Common-Rail DI Diesel engine. The engine was operated at conventional part-load conditions at 2000 rpm, an EGR variation was done and the injected fuel mass was 15 mm^3/cycle. The Nozzle type were conical and flow optimized geometries (ks nozzle) with hole diameters of 0.141 mm, length of hole of 1mm and the Spray Cone Angles were 148° and 120°

Introduction

In Common-Rail DI Diesel Engines, a low combustion temperature process is considered as one of the most important possibilities to achieve very small emissions and optimum performance. To reduce NOx and Soot strongly, it is necessary to achieve a homogenization of the mixture in order to avoid the higher local temperatures which are responsible for the NOx formation [1]. Through the homogenization it is also possible to obtain a stoichiometric air-fuel ratio in order to significantly reduce the Soot emissions. One way to achieve this homogeneous condition is to start injection very early together with the use of higher EGR rates. The direct effect of these conditions cause a longer ignition delay (this is the time between start of the injection and auto-ignition during physical and chemical sub processes such as fuel atomization, evaporation, fuel air mixing and chemical pre-reactions take place) so that the mixture formation has more time to achieve a homogeneous state. However there are some problems that must be solved before this concept can be use completely. The first problem consists on the higher production of HC and CO emissions, due to spray is impinging onto the wall surface. The second problem consists on the position of the combustion phasing, which take place before the top death center and this situation influences negatively the engine efficiency. Therefore is necessary to develop many strategies in order to solve mainly these two problems. [2]. In Previous Works was found optimal spray cone angle and piston bowl geometry, now this work try to find an optimal injection strategy.

Experimental Setup and Measurement Techniques

The experimental investigation of the effect of a very early pilot injection on pollutant formation in a Common-Rail DI Diesel engine was carried out on a production-type GM FIAT 1.9 l CDTI ECOTEC Diesel engine. The 4-cylinder engine utilizes a Common-Rail fuel injection system, variable geometry turbocharger (VGT), an exhaust gas recirculation system, and an intake throttle valve. The engine has four valves per cylinder, centrally located injectors, and a re-entrant type combustion chamber. All relevant engine data are given in Table 1. The mounting of the engine on the test bench is shown in Fig. 1. The production of this engine is certified to meet EURO IV emission standards.

Engine Type	DI, 4-cylinder, charged, 4-stroke
Bore [mm]	82.0
Stroke [mm]	90.4
Displacement [cm^3]	1900
Compression Ratio	18.3
Combustion Chamber	Re-entrant type
Max. Power [kW (PS)]	110 (150) @4000rpm
Max. Torque (Nm / min^{-1})	320 / 2000-2750
Injection System	Bosch Common Rail
Max. Rail Pressure [bar]	1600 bar
Nozzle hole diameter [mm]	0.141
Injector Nozzle	7 holes
Hydraulic flow rate [cm^3 (30s) at 100 bar]	440

Table 1. Engine specifications and injection sys tem specifications

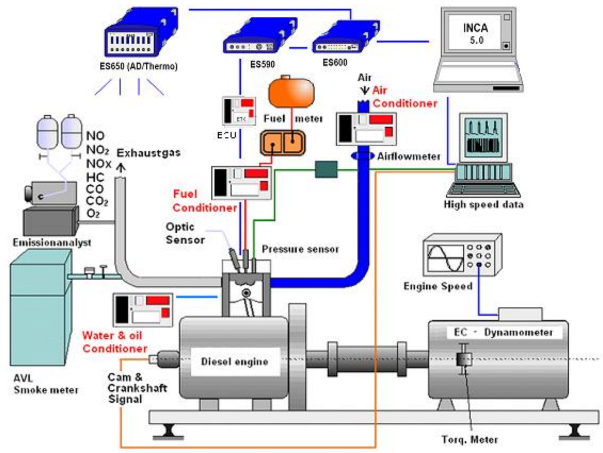


Figure 1. Engine test bench

The engine is equipped with a second-generation Bosch Common-Rail injection system that was used for all experiments reported in this study. Regular Diesel fuel was used in the experiments. A summary of the most important properties of the used Diesel fuel is shown in Table 2.

Cetane number	53.6
Density at 288K (kg/m^3)	834.2
Viscosity at 313K (mm^2/s)	2.892
Distillation $T_{50\%}$ (K)	539.7
Distillation $T_{95\%}$ (K)	619.0
Sulphur (mg/kg-fuel)	9.0
Lower Heating Value (MJ/kg-fuel)	43.163

Table 2. Fuel properties

A Common-Rail fuel system allows for variable pressures (up to 1600 bar), timing, and numbers of injections. Second-generation Bosch injector systems allow for up to five injections (for example, two pilot, one main, and two post injections) per cycle. VGTs have flexible vanes, which move and let more air into the engine, depending on the load. This technology increases both performance and fuel economy. Turbo lag is reduced, as the turbo impeller inertia is compensated using VGT along with an EGR valve. An intake throttle valve supports high flow rates of exhaust gas recirculation. According to conditioning modules for engine testing, the following applications were used:

- Intake Air Conditioning - Fuel Conditioning and Measurement - Engine Oil Conditioning and Engine Coolant Conditioning.

The air-flow rate was measured using a laminar flow element. AVL 733, a dynamic fuel meter, was used for fuel metering. An air-conditioning system determined and maintained the preset temperature and pressure of the intake air. Pressure data was collected for one cylinder. Measured emission data included smoke number, NO_X, HC, and CO. AVL 415, a variable sampling smoke meter, provided exhaust smoke levels. An engine dynamometer (AC/DC type) was used to measure engine torque. The measuring equipment used in the experiments is summarized in Table 3.

CO, CO2	Advance Options Analysatormodul Magnos 16
NO_X	ECO Physics CLD 700 EL ht
HC	Advance Options FID-Analysatormodul Multi-FID 14 (THC C3)
Particulate matter	Variable Sampling Smoke Meter AVL 415
Fuel	AVL 733

Table 3: Emission and fuel consumption measuring equipment

A Bosch-type flow bench [3, 4] was used to measure the fuel injection rate. Fuel is injected into a tube of constant diameter and known length, filled with liquid fuel. Then, a pressure wave propagates through the tube and provides a signal which is detected by a Kistler piezo electric pressure transducer (type 70061B) mounted close to the nozzle exit. This signal correlates to the instantaneous injection flow-rate. The Piezo signal, fuel delivery pipe pressure, injector energizing time, injector current, and voltage are measured with a fast data acquisition system (sample = 30 kHz, IMTEC company). All measurements are carried out over 2000 single injection events, where the injected fuel is collected and weighted. The measured pressure wave signal is calibrated by the time-integral of the signal which is equal to the averaged injected fuel mass per injection. From a comparison of the injection rate and the current signal, the injection delay and duration can be derived.

Description of experiments

The investigations were carried out for a conventional medium-load point at 2000 rpm, a fuel amount of 15 mm^3/cycle, an external EGR rate variation and 700 bar rail pressure.

In order to get a reference point in the first experiment the fuel mass of 15 mm^3/cycle was injected via a single injection. Secondly, 1/15 of the total fuel mass was pre-injected at a distance (dSOI) of the 70 CA deg respect to the SOI main injection or 80 deg. BTDC, in this case the fuel mass of the main injection was 14 mm^3/cycle and Thirdly, a pilot injection was done 60 deg. BTDC also with a mass fuel of 1 mm^3/cycle and a Main injection with 14 mm^3/cycle. See figure 2

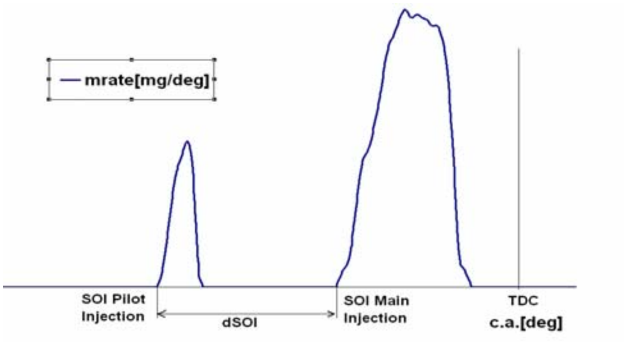


Figure 2: Duration between the starts of two injections

All experiments were carried out first with the spray cone angle 148° and the same experiments also were done with the spray cone angle 120°. See Figure 3.

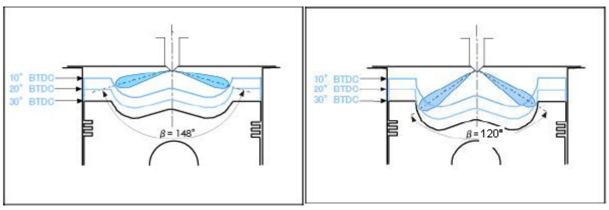


Figure 3. Spray Cone Angle Variation

Results and Discussion

This work was only experimental but numerical support is expected. A very early pilot injection has the intention to prepare good conditions for the combustion. The Soot and NOx emissions for the spray cone angle 148 and 120 are showed in the figure 3 and 4.

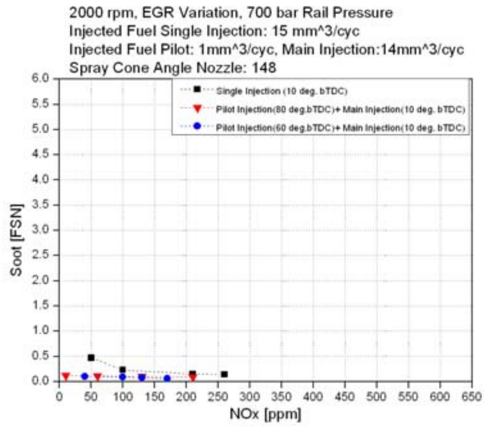


Figure 3. Soot and NOx emissions for SCA 148°.

At a SOI pilot injection by 60 deg. BDTC the Soot and NOx emissions were reduced in comparison to the single injection event, for the second case with SOI 80 deg. BTDC the situation was similar. If the Soot emissions of this experiment with the SCA 148 are compared to the SCA 120 results is possible to see that the Soot and NOx emissions increase due at the higher temperatures resultants of a better quality of the combustion. In the figure 4 is showed that the Soot emissions are reduced by using a pilot injection at 80 deg. BTDC in comparison to the single event. These results could be mean that through the pilot injection the mixture formation is more homogeneous with respect to the single injection.

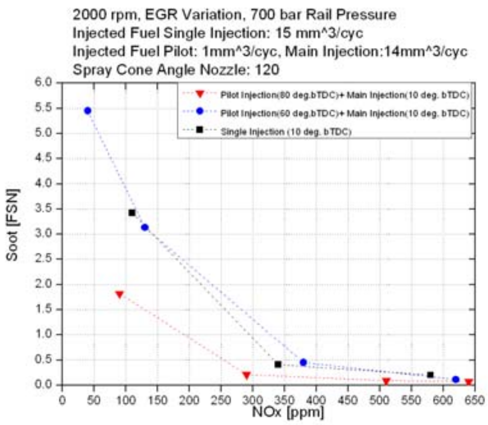


Figure 4. Soot and NOx emissions for SCA 120°.

For the pilot injection events the HC and CO emissions are increased. These results were expected because at very early injection times like 60 or 80 deg. BTDC the pressure, temperature and density in the combustion chamber are very lower and therefore the spray penetration is longer, that means, the fuel spray is impinging on the cylinder-wall. In the figure 5 and 6 the HC and CO emissions are showed for a SCA 148°.

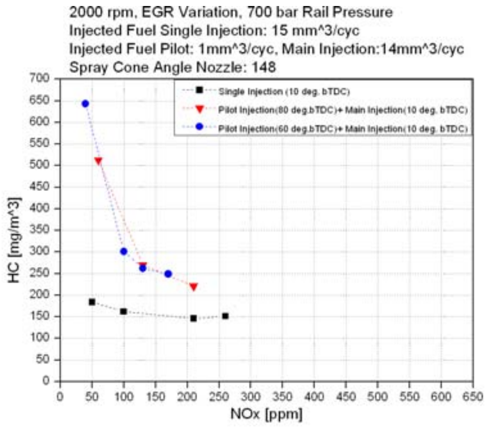


Figure 5. HC and NOx emissions for SCA 148°

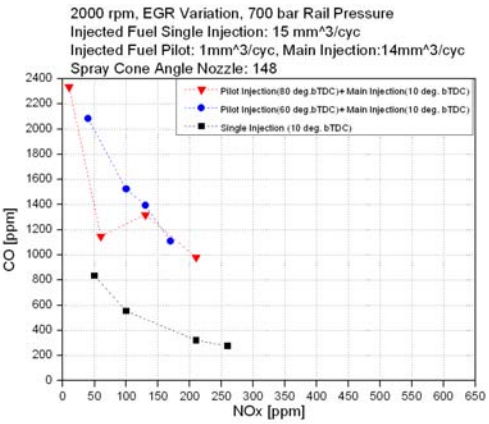


Figure 6. CO and NOx emissions for SCA 148°

However the HC and CO emissions for the SCA 120 are decreased with respect to the SCA 148°. See figure 7 and 8.

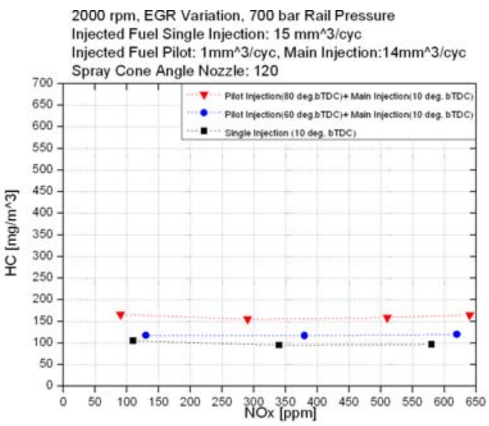


Figure 7. HC and NOx emissions for SCA 120°

Due a better quality of the combustion the HC and CO are lower but unfortunately the NOx emission increases due at the high temperature. In relationship to the pilot events there are not advantages with respect to the HC and CO emissions.

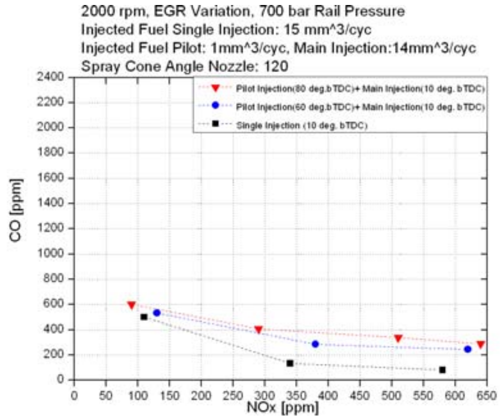


Figure 8. CO and NOx emissions for SCA 120°

For the nozzle with the SCA 148° the IMEP is for the single injection the largest. That means, the fuel consumption is higher for the cases with pilot events. This is a consequence that the spray of the pilot injections is impinging on the cylinder walls. In the figure 9 is showed the IMEP versus NOx for the SCA 148.

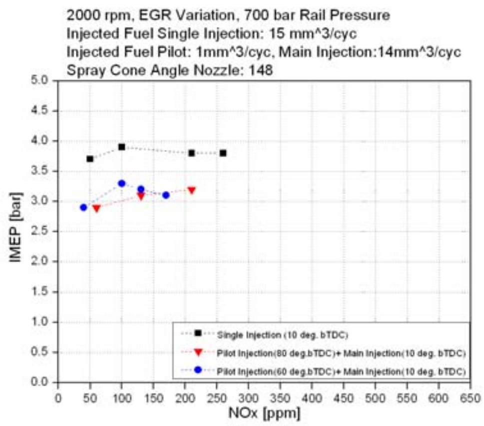
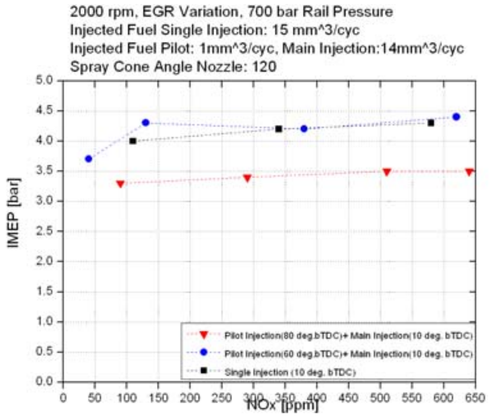


Figure 9. IMEP and NOx emissions for SCA 148°

For the nozzle with SCA 120 the IMEP for the single injection event is similar to the experiment with the SCA 148. However, the pilot injection at 60 deg. BTDC showed a similar value of IMEP in comparison to the single injection.



Summary and Conclusions

An optimal injection strategy is necessary in order to reduce the NOx, Soot, HC and CO emissions and to move the combustion phasing after the top death center. Therefore is necessary to do a lot of experiments using different start of injection times for the main- and pilot injections in order to find the optimal.
Use of a very early pilot injection reduces mainly the Soot and NOx emissions but increase the HC and CO emissions.
A drastic reduction of HC and CO is possible by using of one smaller Spray Cone Angle.

References

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[2] H. Won, A. Vanegas, "Experimental Study of HC Emissions Using Narrow Spray Cone Angles and Different Surrogate Fuels in Low Temperature Diesel Combustion Systems FISITA 2008 World Automotive Congress, September 2008 Munich Germany.

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