ETHANOL AND DIESEL FUEL IN EURO5 SINGLE CYLINDER RESEARCH ENGINE

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Abstract

Experiments were conducted on a single cylinder compression ignition engine using European diesel in-cylinder blended with bio-ethanol in order to realize the PCCI combustion. Diesel was injected in the combustion chamber by Common Rail injection system and bio-ethanol in the intake manifold by commercial port fuel injection system. The engine operating conditions consisted of bio-ethanol injected at 3.5 bar and one diesel injection carried out at 800 bar. The engine speed was set at 1500rpm. The effects of different start of injection of diesel were studied by means of a simultaneous in-cylinder heat release study and high-speed visualization of total chemiluminescence, OH and CH radicals. Advancing the start of the diesel engine the change from fully premixed to a mixing controlled combustion was observed. Moreover, the emission of radicals decrease indicating a better mixing and low pollutant formation just into the cylinder.

Introduction

Particulate matter (PM) is an air toxic and probable carcinogen. This has led to serious consideration on seeking alternatives to replace diesel fuel for diesel engines, either in part or in full, to reduce PM emission. Different approaches are doing based on oxygenates fuel or applying new combustion mode in the engine. Both have been considered based on their availability, price, and compatibility with present engine. Among the fuels, biodiesel and ethanol are the most widely investigated ones. Among the combustion mode, premixed charge compression ignition (PCCI) and homogeneous charge compression ignition (HCCI) have been shown to be promising strategies to simultaneously reduce NOx and soot emissions while realizing improved fuel economy. In particular, PCCI combustion uses high levels of pre-combustion mixing to lower both NOx and soot emissions by ensuring low equivalence ratio and low flame temperatures. The high level of pre-combustion mixing results in a primarily kinetics controlled combustion process.
Significant amount of research has been carried out on the application of ethanol–diesel blends to diesel engines. However, a solvent is normally required for blending ethanol with diesel fuel. The blended fuel can lead to a reduction in smoke and particulate matter (PM), an increase in total hydrocarbon, while carbon monoxide and nitrogen oxides could increase or decrease depending on the engine type and operating conditions [1,2].

In this work, optical characterization was performed in a single cylinder transparent DI diesel engine equipped with the head of Euro5 commercial engine and the last generation CR injection system. The engine was fuelled with diesel fuel in the combustion chamber and pure bio-ethanol in the intake manifold in order to realize premixed charge compression ignition (PCCI) combustion [3].
Optical measurements allowed having detailed information about the combustion chemistry. In particular, in HCCI/PCCI engine research, where combustion is a chemical-reaction-governed process, the importance of knowledge of chemical species and kinetic mechanisms is required.
The visualization of combustion, the detection of the visible flame and of the radical at specific wavelength, the analysis of the chemiluminescence images allowed a better understanding of combustion processes. Emission of many combustion species are characterized by band spectra in the visible and UV regions. The peaks of intermediates and products of combustion such as OH, HCO, CH2O, CH, C2 and CO-O are present in the visible and UV regions [4].

Experimental apparatus and procedures

A single-cylinder (SC) optical engine equipped with the combustion system architecture and injection system of a four-cylinder, 1.9 liter, Euro 5, commercial diesel engine was used. The engine has been also equipped with a Common Rail injection system managed by a fully opened electronic control unit (ECU). The engine layout with the experimental apparatus is shown in Figure 1. Moreover, the engine specifications are reported in Table 1. The optical engine utilized a conventionally extended piston with a piston crown window of 46 mm diameter which provided full view of the combustion bowl by locating an appropriate 45° UV-visible fixed mirror inside the extended piston. The window was made of UV-grade fused silica. Moreover, the combustion bowl volume and the bowl wall shape were the same of the production engine. The injection system specifications are reported in Table 1. In addition, the production intake manifold of the engine was modified to set an electronic port fuel injector (PFI) typical of those used in modern spark ignition engines. It was applied directly into the non-swirl actuated intake port of the cylinder 3 and an image of the injector tip protrusion is reported in Figure 1. The gasoline injector was a production one suitable for gasoline and E85 fuel. It was fed by an electrical pump able to reach up to 3.5 bar injection pressure. It was used with pure ethanol. The CR injection system was controlled by the ECU and another system manages the PFI. In particular, the shaft encoder was used to transmit the crank shaft position to the delay unit for the electronic control. The delay unit controlled the injector generating a pulse width that drove it in terms of both the injection timing and the fuel quantity of the injection event.

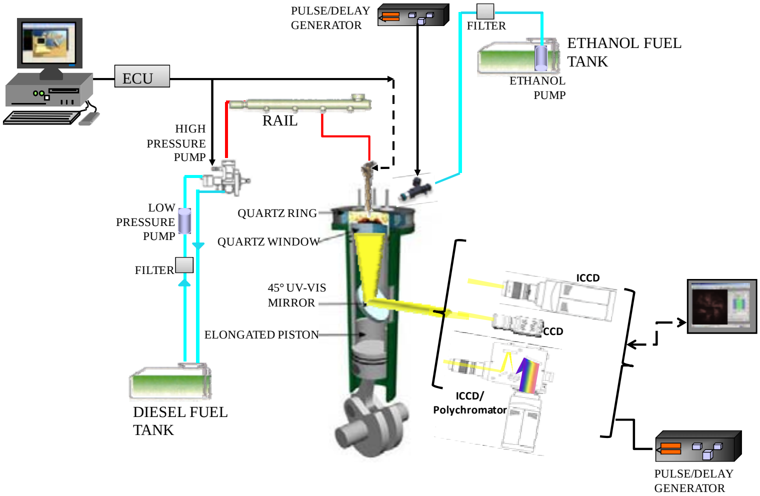

Figure 1. Experimental setup

Table 1. Engine and injection systems specifications

Engine Type	4-Stroke Single Cylinder
Bore	8.5 cm
Stroke	9.2 cm
Swept volume	522 cm3
Combustion bowl	19.7 cm3
Vol. compression ratio	16.5:1
Diesel injection system	Common Rail
Injector type	Solenoid driven
Number of holes	7
Cone angle of fuel jet	148°
Hole diameter	0.141 mm
Rated flow at 100 bar	440 cm3 / 30 s
Ethanol injection system	Port Fuel Injection
Number of holes	10
Cone angle	14°
Separation angle	22°
Rated flow at 3 bar	202 cm3 / min

In order to analyze the injection signal, a Hall-effect sensor was applied to the line of the solenoid current, A piezoelectric pressure transducer was set in the glow plug seat of the engine head in order to acquire the cylinder pressure in motored and fired condition. Opacity and regulated gaseous emissions were measured with conventional systems by means of probes placed in the exhaust pipe.
Digital imaging and broadband ultraviolet–visible flame spectroscopy

measurements were performed by the experimental setup shown in Figure 1.
In particular, in order to examine the temporal and spatial evolution of visible flames, a CCD camera of 640 x480 pixels was used. The camera had a high sensitivity in a wide visible range. The UV–visible flame emission was detected via a ICCD camera of 512x512 pixels that had a very good sensitivity in the UV wavelength range. The intensifier gate duration was of 51 μs. Finally, radicals imaging were acquired with the UV objective, ICCD camera, and band pass filters chosen at characteristic wavelength of OH (λ = 309 nm), HCO (λ = 330 nm), and CH (λ = 431 nm). Filters had different transmission ratio: 15% for OH, 25% for HCO, and 45% for CH. Synchronization of the engine with the ICCD and CCD camera was obtained by a delay unit connected to the signal coming from the engine shaft encoder. The synchronization system could be adjusted to obtain single images at any desired crank angle within the half degree resolution of the shaft encoder.

Experimental results

In Table 2, the operating conditions investigated in the optical engine running at 1500 rpm are reported.

Table 2. Engine operating conditions

OP	Fuel 1	SOI [CA]	ET [μs]	Fuel 2	SOI [CA]	DOI [CA]
B2	Diesel	-6°	380	Ethanol	3°	30°
B3	Diesel	-10°	380	Ethanol	3°	30°

The two operative conditions were selected as characteristics of mixing controlled combustion, the first, and of premixed combustion, the second.
In Figure 2 the histories of in-cylinder combustion pressure, injection signals and rate of heat release curves for the two operating conditions investigated are reported. Even if the amounts of injected fuels are the same for both the strategies, however they produce very different indicated mean effective pressure (IMEP) meaning that the fuel burning differently. In particular, B2 strategy shows the higher IMEP than B3. Moreover, analyzing the ROHR curves, it is possible to observe that B2 has a large and greater peak characteristic of mixing controlled combustion, while B3 has a narrow and with very fast increasing rate ROHR characteristic of premixed combustion.

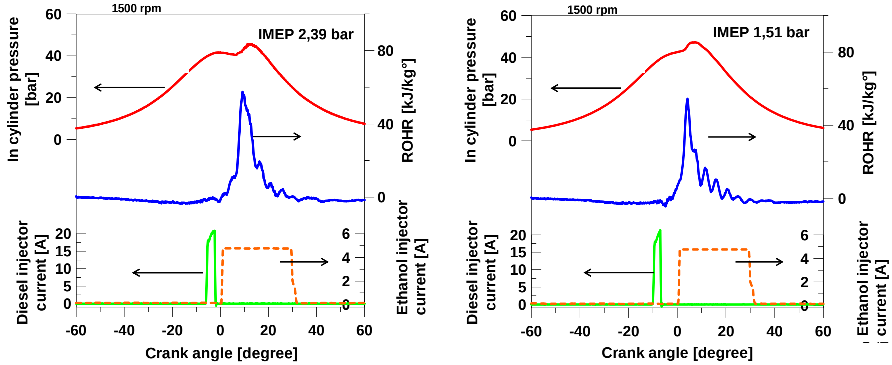

Figure 2. Histories of in-cylinder pressure, ROHR and combustion temperature for the engine operating conditions investigated, B2 on the left, B3 on the right.

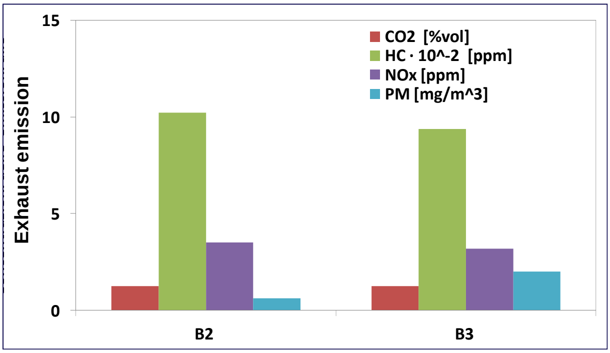

Figure 3. Pollutant emissions at the exhaust of the engine

In Figue 3 the pollutant emissions measured at the exhaust pipe of the single cylinder engine are reported. The CO2 emissions are the same because in the engine the same amount of both diesel and ethanol is injected. HC are very high for both the strategies, in fact their values are divided by 100 in order to represent the data on the same graph. This is due to the large amount of ethanol injected in the intake manifold that moves into the crevice and in the dead volume and probably did not participate to the combustion. The combustion occurs mainly in the bowl. NOx and PM are also very low with respect to those characteristic of modern common rail diesel engine on the market. However, the lowest was measured for B2 strategy, probably in this configuration the diesel fuel is well distributed in the combustion chamber, well homogenized with the ethanol/air charge and, finally, ignite well all the mixture. Moreover, the combustion temperature is sufficiently low to not activate the formation mechanism of the NOx.
In Figure 4, the natural emission images of the combustion detected with the CCD camera (1st row) and ICCD camera (2nd row) for the B2 strategy are reported. In the same figure also the spatial distribution of CH radical at 430 nm and of OH radical

at 310 nm, respectively, acquired with ICCD and ad hoc filters are shown. In previously study the presence of the radicals were recognized by means of spectroscopic measurements [5]. For each row, the maximum adopted for the representation of the images is reported on the right side of the figure. Visible images did not furnish a lot of information regarding the evolution of the luminous combustion. Some bright spots are visible under the nozzle tip and close to the nozzle. This is characteristic of the Mini-sac nozzle that produce rich fuel zone at the exit of the nozzle hole also when the injection is finished. Much more information can be detected by the analysis of the UV-Vis images. Even if the intensity is very high under the nozzle location, strong chemical activity is noted in the whole combustion chamber. This means that all the mixture in the bowl is reacting produce locally low temperature combustion regime. The combustion is mainly driven by the evolution of the chemical reaction in the bowl and the mixture burns due to the autoignition of the diesel fuel. For this reason, the analysis of radicals was necessary. In particular, the CH distribution was detected close to the bowl wall where the tip of spray impinged. This radical is characteristic of the zone with high vapour fuel concentration. On the other hand OH fills almost the entire combustion chamber, and it is characteristic of autoignition of the mixture.

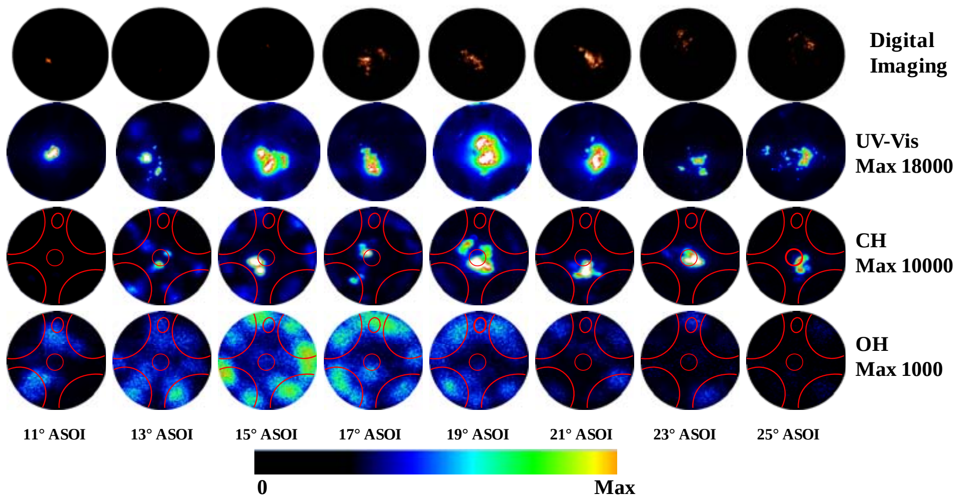

Figure 4. Combustion images by means of CCD and ICCD cameras (1st and 2nd rows) and images of CH and OH radicals (3rd and 4th rows), respectively, for B2 operating condition

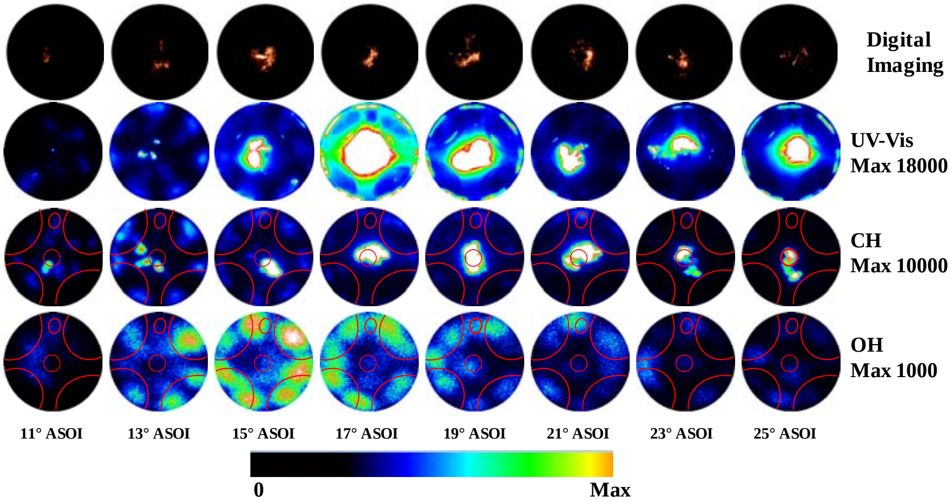

Figure 5. Combustion images by means of CCD and ICCD cameras (1st and 2nd rows) and images of CH and OH radicals (3rd and 4th rows), respectively, for B3 operating condition

In Figure 5 the images of the combustion of the B3 strategy are reported. In this case they show very high emission intensities, in the visible as well as in the UV-Vis wavelength range. This is characteristic of a mixture that burns producing high soot flame and this is also in good agreement with the exhaust emissions analysis. Moreover, the radical images are higher than the previous ones, thus flame with higher concentration of vapor fuel and more premixed are produced in this case.

Conclusion

Varying the SOI of diesel fuel, the change from a premixed combustion to a mixing controlled one was observed. Higher light emission of combustion in the UV-Vis wavelength range was detected for B3 injection strategy. It is due to the impingement of fuel that produces bad mixing of the diesel. For this reason, also the visible flames emissions for B3 strategy resulted bigger than B2 ones and this justify the higher soot production of B3. The bad mixing of the air/ethanol with the diesel fuel produce also a high emission of the radicals, CH and OH, and it is responsible of minor homogenization of the mixture than the B2 strategy.

References

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