HCCI operation of an optically accessible diesel engine fuelled with RME fuel

Ezio Mancaruso, Bianca M. Vaglieco
Istituto Motori
CNR – Napoli (Italy)

Introduction

In order to overcome the pollutant emission limitations the use of homogeneous charge compression ignition (HCCI) mode must be considered in direct injection diesel engine using biodiesel fuel. HCCI mode reduces PM and NOx emissions without penalize the performances [1]. This occurs because the combustion develops with low temperature and burns a premixed air/fuel mixture. Biodiesel is a renewable fuel that can be produced from a variety of vegetable oils including rapeseed oil, soybean oil, sunflower oil and palm oil [2]. The goal of this paper is the evaluation of the HCCI combustion in an optically accessible diesel engine realized with four small early injections using RME fuel.

Experimental apparatus

The optically accessible engine used during experiments was a single cylinder, direct injection, four-stroke, diesel engine, with EURO IV multi valves production head. The engine used a classic extended piston with piston crown window (46 mm diameter) and a 45° UV-visible mirror located inside the elongated piston. The engine was equipped with Common Rail injection system and a fully flexible Electronic Control Unit (ECU) that controlled the number of injections up to 5 per cycle. To analyse the injection signals, a Hall-effect sensor was applied to the line of the solenoid current and a piezoelectric pressure transducer was located in the injection line between the rail and the injector. To acquire the cylinder pressure in motored and fired condition, a piezoelectric pressure transducer was set in the glow plug seat of the engine head. Imaging measurements from ultraviolet (UV) to visible were performed by means of the optical set up shown in figure 1.

Two different CCD cameras, with a different capability, were used. The first (ICCD) had high sensibility both in the UV and visible range. The intensifier-gate duration of 41 µs was used in order to have a good accuracy in the timing of the onset of the combustion process. Previous investigations showed the presence of characteristics radicals during the low temperature and premixed combustion development [3].

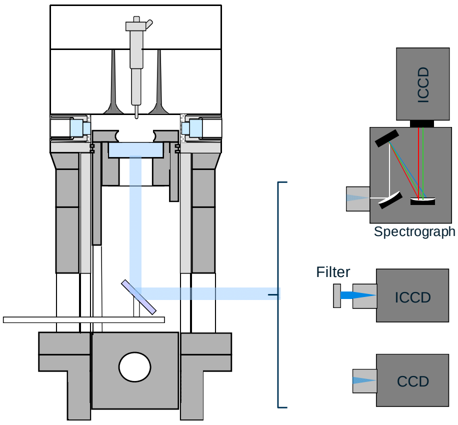

Fig. 1: Experimental setup.

In particular, the ICCD camera was used and coupled with narrow filters corresponding to λ=310 nm for OH, λ=330 nm for HCO* and λ=431nm for CH, respectively. The second CCD was sensible in the visible. Moreover, two colour pyrometry method was applied by using an “ad hoc” filter in order to evaluate soot temperature and concentration [4]. Synchronization of engine with ICCD and CCD camera was obtained by the unit delay connected to the engine shaft encoder. The effect of RME fuel with respect to reference fuel (REF) at two engine speeds, 1500 and 2000 rpm, respectively, and varying the injection pressure was analysed.

Results and discussions

In figure 2 typical histories of cylinder pressure, rate of heat release and drive current of HCCI at 2000 rpm for REF and RME fuels, respectively, are reported. In particular, in order to realize a well mixed air/fuel charge in the cylinder four early injections were performed during the compression stroke. The same fuel amount was injected varying the injection pressure, even if higher quantities for the engine operation with RME fuel because of its lower energy content. It can be noted that the rates of heat release have typical shape of HCCI combustion with two well resolvable peaks not correlated with the injection strategy investigated. The first is characteristic of low temperature reactions that occur in the chamber at autoignition; and the second is due to the development of high temperature reactions [3].

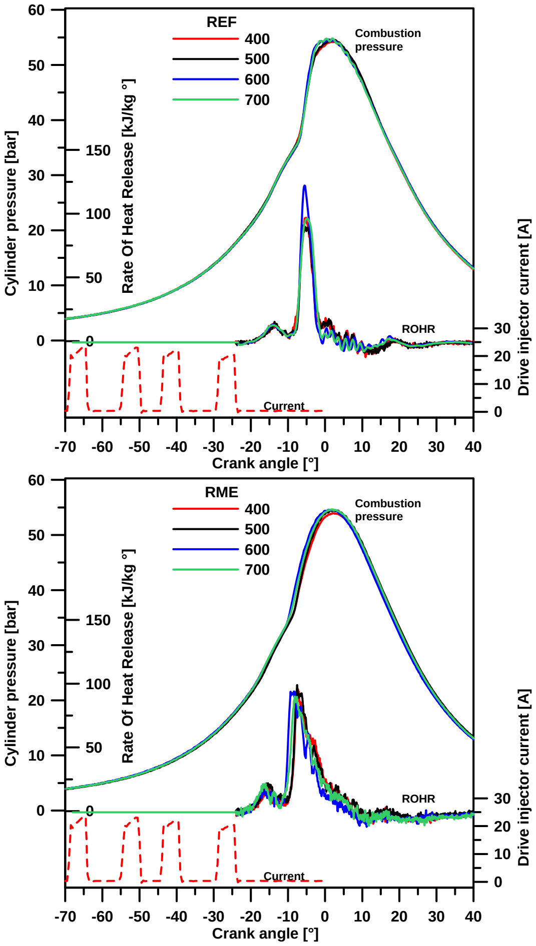

Fig. 2: Combustion pressure, rate of heat release and drive current at 2000 rpm for REF (up) and RME (down) fuels at several injection pressures.

To examine the temporal and spatial evolution of HCCI combustion digital imaging measurements from UV to visible were performed. In figure 3 the images of visible combustion and the soot KL factor are reported. They are related to RME fuel, the engine speed of 2000 rpm and an injection pressure of 500 bar. In figure 3, the first column shows the flame evolution, it can be noted the presence of luminous spots randomly distributed in the bowl. Increasing the crank angle, the luminous spots move in the cylinder, due to the air swirl motion, and increase their density in the whole chamber. These bright spots are distributed not only in the bowl but also in the space between the engine head and the top of the piston [3]. By means of the two colour pyrometry method, the soot KL factor proportional to the soot mass concentration were calculated and reported in figure 3. The soot mass concentration in the cylinder is very low during the whole combustion process. In particular, the maximum intensity is detected at 6° before top dead center (BTDC).

Previous analysis of extinction and chemiluminescence measurements showed that the premixed combustion process is widely dominated by the presence of OH radical [3]. For this reason, the UV images were recorded by means a filter (bandwidth 10nm) at the characteristic emission wavelength of OH (310 nm). In figure 3, the OH images and the relative maximum intensity at the lower left corner are reported.

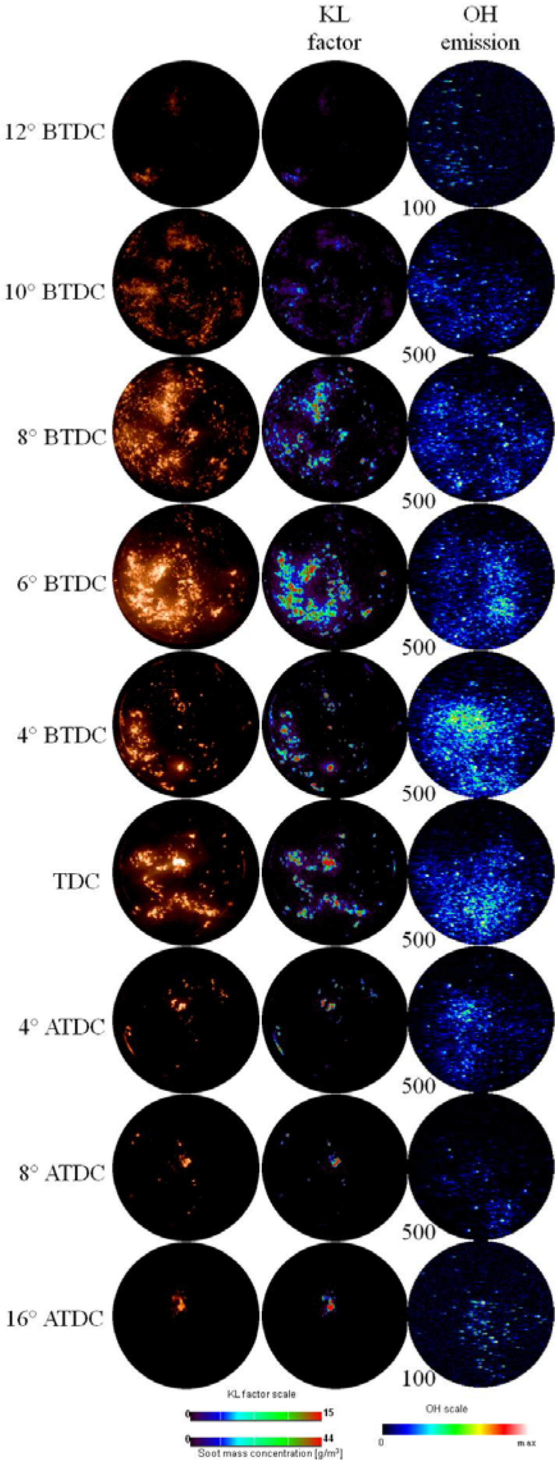

Fig. 3: HCCI combustion images, KL factor proportional to soot mass concentration, and OH intensity for RME fuel at 2000 rpm.

They show very low emission because only 15% of incident light passed through the filter. The OH radical is detected close to the bowl wall at the start of combustion, then it fills the whole chamber, and it shows maximum intensity at 4° BTDC, three crank angle degrees later than the heat release peak.

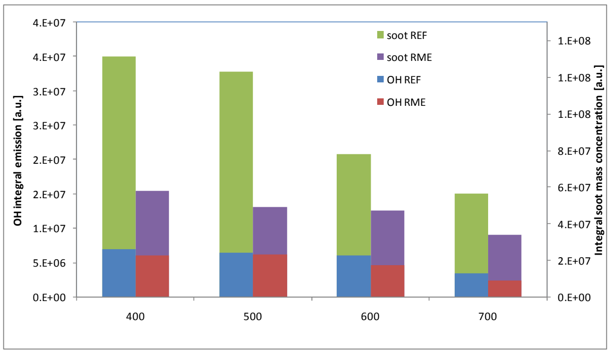

Fig. 4: Integral OH radical and soot mass concentration measured in the combustion chamber at 2000 rpm for REF and RME fuels at different injection pressure.

In figure 4 the integral OH measured in the combustion chamber at 2000 rpm and for several injection pressures are reported. The integral concentrations were computed for both REF and RME fuels. It can be noted that increasing the injection pressure the OH intensity decreases for both fuels and the lowest intensity is detected for RME at 700 bar. Previous paper showed that OH radical was responsible of the soot oxidation in the chamber [5]. For this reason the integral soot concentrations are reported in same figure. The higher injection pressure produces better atomization of the fuel, thus lower soot production. Moreover, the oxygen content of the RME fuel contributes strongly to the reduction of soot. Finally, the lowest OH concentration is detected at the lowest soot concentration, due to the higher in-cylinder soot reduction.

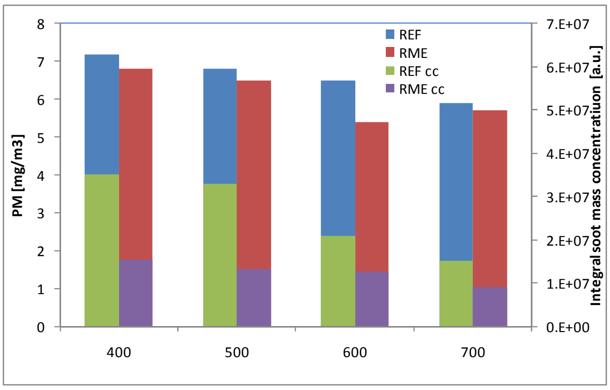

Fig. 5: Comparison of in-cylinder soot mass concentration and PM exhaust emission at 2000 rpm for REF and RME fuels at different injection pressure.

Figure 5 compares the integral value of soot concentration curves with the PM measured at the exhaust pipe of the optical engine by means of an opacimeter. The data in Figure 5 indicate similar trends in soot emission even if the difference between the two fuels is less evident at the exhaust. This is due to the high unburned hydrocarbon concentrations of the homogeneous combustion.

In conclusion, the use of oxygenated fuel helps to keep low the production and emission of HC with consequently positive effect on the emission of particulate matter.

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