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A spectroscopy study of gasoline partially premixed compression ignition spark assisted combustion

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HIGHLIGHTS

- PPC combustion combined with spark assistance and gasoline fuel on a CI engine.
- Chemiluminescence of different chemical species describes the progress of combustion reaction.
- Spectra of a novel combustion mode under SACI conditions is described.
- UV–Visible spectrometry, high speed imaging and pressure diagnostic were employed for analysis.

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ABSTRACT

Nowadays many research efforts are focused on the study and development of new combustion modes, mainly based on the use of locally lean air–fuel mixtures. This characteristic, combined with exhaust gas recirculation, provides low combustion temperatures that reduces pollutant formation and increases efficiency. However these combustion concepts have some drawbacks, related to combustion phasing control, which must be overcome. In this way, the use of a spark plug has shown to be a good solution to improve phasing control in combination with lean low temperature combustion. Its performance is well reported on bibliography, however phenomena involving the combustion process are not completely described. The aim of the present work is to develop a detailed description of the spark assisted compression ignition mode by means of application of UV–Visible spectrometry, in order to improve insight on the combustion process.

Tests have been performed in an optical engine by means of broadband radiation imaging and emission spectrometry. The engine hardware is typical of a compression ignition passenger car application. Gasoline was used as the fuel due to its low reactivity. Combining broadband luminosity images with pressure-derived heat-release rate and UV–Visible spectra, it was possible to identify different stages of the combustion reaction. After the spark discharge, a first flame kernel appears and starts growing as a premixed flame front, characterized by a low and constant heat-release rate in combination with the presence of remarkable OH radical radiation. Heat release increases temperature and pressure inside the combustion chamber, which causes the auto-ignition of the rest of the unburned mixture. This second stage is characterized by a more pronounced rate of heat release and a faster propagation of the reactions through the combustion chamber. Moreover, the measured UV–Visible spectra show some differences in comparison with the other stages. The relative intensities in of spectra from different combustion radicals have also been related to the different combustion phases.

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Nomenclature

CI	Compression Ignition
ICE	Internal Combustion Engine
EGR	Exhaust Gas Recirculation
PPC	Partially Premixed Combustion
SACI	Spark Assisted Compression Ignition
ROHR	Rate of Heat Release
CAD	Crank Angle Degree
ACV	apparent combustion velocity

1. Introduction

Nowadays the automotive scientific community focuses part of their efforts on the investigation of new combustion modes [1] with the aim of reducing fuel consumption and emissions in Compression Ignition (CI) diesel engines [2,3]. These modes are mainly characterized by taking place under homogeneous locally lean conditions which, combined with high exhaust gas recirculation rates, provide low combustion temperatures. As a consequence, NOx and soot formation are reduced while fuel consumption and efficiency improve [4].

In spite of their benefits, these combustion concepts present some challenges that must be overcome before their practical implementation in ICEs. The main limitation is obtaining a proper combustion phasing and control over a wide range of engine load and speed. Highly-premixed combustion modes in CI engines are dominated by chemical kinetics, which are directly dependent on temperature and chemical composition of the mixture. As a consequence, achieving the proper ignition conditions requires both adequate mixing and temperature of the charge. To solve this problem, different strategies have been proposed [5–7]. Temperature can be controlled by intake air heating or modifying the compression ratio. Other strategies like control of EGR rate [27] or the amount of trapped combustion gases also modifies mixture composition. Multiple injection strategies and combinations of different fuels have also been investigated. However, the majority of the techniques mentioned cannot provide precise control over the combustion phasing, since they require time scales too large to achieve cycle-by-cycle control.

All previous actions try to compensate the high chemical reactivity of the diesel fuel that does not provide enough mixing time before the start of combustion. Thus, recent studies have tried to overcome these disadvantages by using fuels with different reactivities. Partially Premixed Combustion (PPC) is a novel combustion strategy with the main characteristic being the use of a low reactivity fuel [8–10]. This combustion mode is in transition between normal diffusion combustion in CI engines and Premixed Charge Compression Ignition (PCCI). It allows a high degree of fuel–air mixing before ignition but the charge is not completely homogeneous [11,12]. Nevertheless, while all these solutions provide some control of the combustion phasing, they still cannot deliver the required cycle-to-cycle control capability of these partial or fully premixed combustion processes. Moreover, when a very low reactivity fuel is used [13,28], it is not possible to achieve stable engine operation for light and mid load conditions.

Spark assisted combustion phasing and control has been investigated for controlled auto-ignition (CAI) implementation in port fuel injection SI engines. The spark plug has been used to supply the necessary energy for achieving a controlled auto-ignition process with a method referred to as Spark Assisted Compression Ignition (SACI). In this mode, the combustion process is composed of a first growth of a reaction kernel, due to the energy supplied by the spark, which leads to the start of a propagating flame. The flame propagation combustion consumes part of the fuel, releasing energy that increases the mixture temperature and provokes its auto-ignition. Since flame propagation is generally slower than auto-ignition, this mechanism reduces the overall heat release rate. Previous experimental work using spark ignition engine architecture [14,15] and moderate reactivity fuels suggests that this method can provide good combustion phasing while the response time is short enough for cycle-by-cycle application [16,17].

In the present work, combustion phasing control by means of a spark plug ignition system is integrated on a CI engine working in

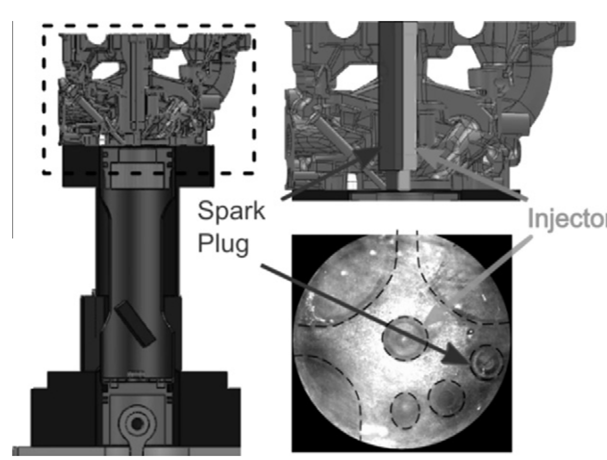

Fig. 1. Sketch of the single cylinder optical engine and the modified cylinder head.