Simultaneous PLIF imaging of formaldehyde and high-speed chemiluminescence within a Rapid Compression Machine

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The Homogeneous Charge Compression Ignition (HCCI) and Spark Induced Compression Ignition (SICI) combustion processes constitute advanced operating modes for automotive engines implying both high thermal efficiency and low NOx and soot emission thanks to the combustion of lean or diluted mixtures featuring a relative homogeneity [1]. The control of self-ignition mechanisms implied in such operating modes as well as the maximum heat release rates constitutes a major challenge for its practical application to engines.

The Rapid Compression Machine (RCM) employed in this work appears as a relevant device to study such modes of combustion since the mixture composition and pressure can be varied within a large range of conditions. Furthermore, the present device features large optical accesses allowing the visualization of the full volume of the chamber after the end of the compression stroke. This provides ideal conditions for studying the combustion process by means of optical diagnostic methods [2].

In the case of long chain hydrocarbons, self-ignition is often achieved in a two-stage process. A first rise in pressure is observed coupled with low light emission. This first peak of activity corresponds to pre-ignition reactions. It is described as the cold flame and is the prelude to the main stage of combustion, called hot ignition. Formaldehyde constitutes one of the most important combustion intermediate species, which are formed in the first stage of hydrocarbon oxidation. Since formaldehyde is completely consumed during hot ignition, it is well-suited as a tracer species of cool-flame regions.

Simultaneous planar laser-induced fluorescence imaging of formaldehyde and high-speed chemiluminescence have been performed in the combustion vessel of the RCM in order to study respectively the cool flame and hot ignition phenomena. Flame propagation is also monitored by chemiluminescence imaging. Iso-octane – air mixture with a fuel equivalence ratio equal to 0.5 is considered for the experiments. Frequency-tripled laser radiation at 355 nm from the Nd-YAG laser is used for excitation of formaldehyde. The resulting 2D fluorescence signal is detected with ICCD camera equipped with 105 mm UV Nikon lens and a longpass filter allowing detection above 395 nm. High-speed camera placed perpendicularly to the semi-transparent mirror enables detection of chemiluminescence integrated through the depth of the vessel.

The aim of the present work is to highlight the complementarity between apparition of cool flame and the flame propagation. Experiments are performed for different delays after start of the machine to cover the entire combustion cycle. From both early and late stage of the process, formaldehyde imaging appears as the “negative” of flame chemiluminescence. Apparition of formaldehyde signal also coincides with the first rise in pressure identified as the cold flame. Self-ignition then SICI regimes are tested. In both cases, the results clearly evidence complementarity between the presence of formaldehyde and zones featuring chemiluminescence as a result of either hot ignition or flame propagation.

From a quantitative point of view, the calculation of apparent flame velocities of the reaction zones is enabled, focusing on the early stage of the combustion process.

From a more general point of view, the results obtained by two dimensional formaldehyde PLIF and chemiluminescence imaging provide insights into the understanding of complex interactions between temperature heterogeneities, aerodynamics and the reactive processes as they take place within engines operating in the HCCI or SICI regimes.


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