AN EXPERIMENTAL KINETIC STUDY OF PLASMA-ASSISTED COOL FLAMES IN A RAPID COMPRESSION MACHINE

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Introduction

In new engine technologies, such as PPCI or HCCI configurations [1], the initiation of combustion is highly dependent on the chemical kinetics associated with Low Temperature Combustion (LTC). This combustion regime is associated with degenerate chemical branching through the formation of highly unstable peroxidic species, the formation of such being constrained by the structure of the initial fuel [2]. This chemical branching results in cool flames, i.e. faint light emission around 400 nm, usually attributed to the formation of excited formaldehyde, as well as a moderate temperature increase. Difficulties in ensuring reproducible ignition timing in such engine configurations has triggered interest in plasma-assisted ignition in the LTC regime [3–5].

Among the fuels that have been studied in such conditions, n-heptane is a good example, as it shows high LTC reactivity, is one of the Primary Reference Fuels for octane number measurement, and is often used as a surrogate for diesel fuel. Its LTC chemical kinetics have been studied in several reactors, including flow reactors [6,7], shock tubes [8] or rapid compression machines [9,10].

The possibility to induce ignition of methane or n-butane in high pressure conditions in a Rapid Compression Machine (RCM), by means of local production of excited species and radicals by a Dielectric Barrier Discharge (DBD), has been demonstrated in a recent paper [11]. This work focuses on using the same tools to stimulate the LTC reactivity.

Experimental

The ULille Rapid Compression Machine (RCM) was coupled with a DBD electrode to generate a nanosecond discharge at the end of the compression. The pressure was measured with a Kistler 6052 transducer. Emission spectroscopy was performed through the side window of the RCM, and samples of the reacting mixture were extracted from the reaction chamber during the experiments to measure the concentration profiles of the main stable intermediates with help from gas chromatography – mass spectrometry analysis.

Results

It was found in [11] that at high pressures the discharge develops mainly in the plane of the electrode system. At low pressures the discharge is volumetric: longitudinal structures can be seen propagating from the electrode (left-hand side) towards the piston (right-hand side) in Figure 1.

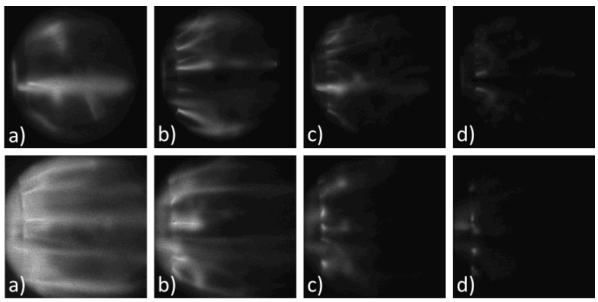

Figure 1: Side imaging of the discharge development in the RCM. a) P_{TDC} = 1.5 bar b) P_{TDC} = 2.1 bar c) P_{TDC} = 2.7 bar d) P_{TDC} = 3.3 bar.

Spectral analysis showed that light emission corresponds to transitions relative to excited N_2 exclusively. In these moderate pressure conditions, using n-heptane as the fuel and with a pulse of negative polarity, a case where a cool flame is induced by the discharge has been identified, as displayed in. Without discharge or with the lowest values of the absolute value of the voltage amplitude at the electrode |U|, the system showed no reactivity. For intermediate values of |U|, the system displayed a cool flame. At higher voltages hot ignition was observed, as in [11]. The absence of reactivity without plasma was verified, ensuring reproducibility of this situation. To gain insight on possible modifications by the plasma of the main reaction pathways associated with n-heptane oxidation in low temperature combustion conditions, the reacting mixture was quenched at selected times after the discharge in separate experiments, and analyzed using gas chromatography techniques. The major intermediate products formed in n-heptane cool flames [9] were detected and quantified, with no new products in comparison to a spontaneous cool flame case observed at higher pressures.

Comparing the concentration and light emission profiles during both a plasma-assisted case and a spontaneous case shows that in contrast with spontaneous cool flames usually observed in RCMs, the plasma-assisted cool flame is propagative by nature.

Conclusions

Plasma-assisted cool flames were generated in a RCM at moderate pressures, by means of a nanosecond DBD discharge, and subject of a detailed experimental study by means of imaging, emission spectroscopy, and chemical analysis of the intermediate species. The results of this study show that under adequate pressure conditions, the DBD electrode system used in this study generates a volumetric discharge with streamers that cross the RCM chamber. The discharge enables initiation of the cool flame reactivity in an otherwise unreactive case. Comparison of these plasma-assisted cool flames with comparable spontaneous cool flames obtained at a slightly higher pressure showed that no new products are formed. Differences in the shape of species and light emission profiles indicate that the plasma-assisted cool flame is propagative by nature. It is believed that the effect of the discharge occurs mainly through the formation of a radical pool that accelerates the initiation steps of the LTC chemical mechanism.

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