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PLASMA-ASSISTED IGNITION KINETICS BELOW SELF-IGNITION THRESHOLD IN HYDROGEN AND HYDROCARBON-AIR MIXTURES

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The paper presents the results of temporal dynamics measurements of hydroxyl radicals in premixed hydrocarbon-air flows excited by a nanosecond pulsed streamer discharge plasma below a self-ignition threshold. The experiments have been conducted for four different hydrocarbons – methane, ethane, propane and butane with equivalence ratio 0.1 at six different temperature points varying from 300 K to 800 K. Using laser induced fluorescence (LIF) technique the measurements of absolute OH radicals concentration dynamics is achieved by adjusting triggering synchronization between pulsed high voltage generator and Nd-YAG laser. The plasma was generated by sequential pulses of high-voltage (~20 kV), short pulse duration (~10 ns) and extremely short rise time (< 1 ns) at repetition rate of 10 Hz. The high reduced electric field guarantees efficient electronic excitation and molecular dissociation, while the picosecond scale rising time greatly improves the discharge stability and helps sustaining uniform nonequilibrium plasma [1]. The streamer discharge in premixed hydrocarbon-air flow results in extra large concentration of OH radicals and only about 10 percent increase of gas temperatures, inferred from nitrogen second positive band system spectra. The experiments gave quantitative information on the hydrocarbon reaction dynamics under self-ignition threshold with high initial concentration of radicals.

The experimental installation for plasma-assisted ignition analysis below the self-ignition threshold consists of a ceramic burner, electrode system, nanosecond high voltage generator and gas (fuel and air) supply system. Gas flows were preheated in thermo–insulated region from 300 K up to 800 K. Mixing chamber and plasma nozzle were made of alumina ceramics for additional thermal and electrical insulation. Discharge in needle–tip geometry was organized along the axis of the premixed flow. Temperature measurements were performed via optical emission spectroscopy together with a thermocouple. The temperature of the flow was stable within ± 10 K in the discharge gap. Flow velocity was 20-30 cm/s which guarantee full mixture replacement between high-voltage pulses.

The discharge started at high voltage electrode and after about 4 ns the streamer channel bridged the discharge gap. Return stroke leads to the potential redistribution along the gap. After this the reduced electric field in the plasma channel becomes lower than the breakdown field (~ 120 Td for room-temperature air) and a slow plasma recombination starts. Typical time of the plasma degradation in this field is several microseconds and this degradation does not effect on the discharge current and gas excitation and dissociation during the pulse (~ 10 ns). When voltage decreases the fast quenching of a main emitting state [2]

$$N_2(C^3) + O_2 = N_2(X^1) + O + O \qquad (1)$$

takes place. The plasma channel becomes invisible (Figure 1). During the discharge between two needle electrodes, the streamer channel stays uniform, which is beneficial to our experiments.

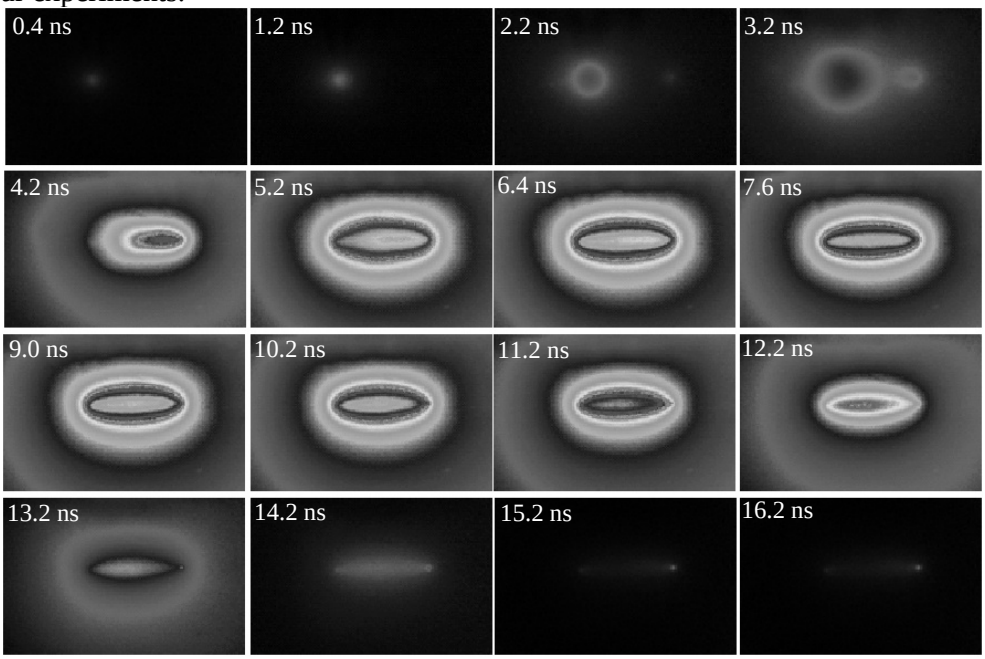

Figure 1. Sequenced ICCD images of plasma discharge development between two electrodes, camera gate is 200 ps. Air, P = 1 atm, U = 20 kV.

Figure 2 demonstrates the OH dynamics for two different hydrocarbons: methane and butane at different temperatures. It is clearly seen that at low temperatures we have faster OH consumption in the butane-air mixture due to low rate constants of reaction of OH with methane. At elevated temperatures chain branching and chain propagation reactions become faster in butane-air mixture and provide a significant fuel conversion even below a self-ignition threshold.

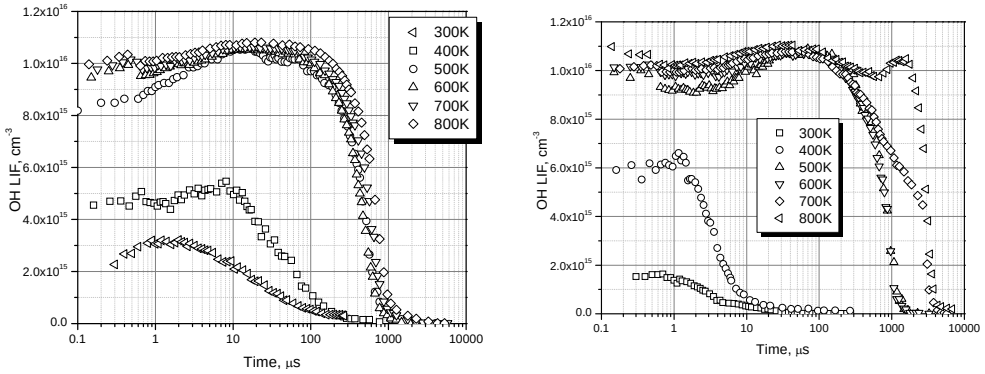

Figure 2. OH dynamics in lean methane-air (1) and butane-air (2) mixtures for different temperatures below self-ignition threshold. P = 1 atm. ER = 0.1

References

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2. I.N. Kosarev, N.L.Aleksandrov, S.V.Kindysheva, S.M.Starikovskaia, A.Yu.Starikovskii, Combustion and Flame, 156 (2009) 221-233