Study of laminar premixed flames in transient electric fields using PLIF and PIV techniques

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The enhancement of the flame stability as well as the pollutant emissions reduction can be achieved by the use of electric fields; however, the ongoing mechanisms are not yet fully understood. In this experimental study laser based measurements such as planar laser induced fluorescence (PLIF) as well as particle image velocimetry (PIV) were used to reveal the basic mechanisms of this interaction.

For this effect the ions and electrons produced by chemionization in the flame front are utilized. They get accelerated depending on their polarity by the electric field. Within a longitudinal arranged setup where a positively charged electrode is placed above a grounded burner, as used in this experiment, the Lorenz Force pushes the positive ions towards the burner rim. This hydrodynamic back pressure caused by the momentum transfer between ions and molecules is in the literature often referred to as the Ionic Wind. At very high electric field strength the transferred momentum could excite other molecules. This energy can be transferred by intermolecular interactions enhancing the production of radicals and thereby directly changes the chemistry of the flame. Therefore, e.g. a change of the flame front thickness is expected. To visualise those changes the flame front was reconstructed from the planar OH- and the formaldehyde-fluorescence signals.

Altendorfner et al. [1] showed for static fields a reduction of the flow velocities of about 1.5 m/s. This deceleration clearly corresponds to the Ionic Wind effect. In contrast, no clear change in the flame front thickness was observed. In the presented experiments the test rig was expanded with a high voltage, high frequency switch with which a transient DC-field could be applied in order to determine response times of the flame. This temporal behaviour is of particular interest for modelling approaches estimating the momentum transfer via Ionic Wind or change in chemistry respectively. To reveal the development of the deceleration the on- and off-pulse of the applied electric field were resolved in 2 ms increments as the electric field strength was kept constant at 120 kV/m (with a supply voltage of 6 kV).

From the OH-PLIF-images temporal information of the flame structure can be calculated, which is more distinct compared to the scalar velocity field, since the flow direction also changes. Moreover, when the electric field is applied a disturbance is evident propagating downstream through the flame and the exhaust gas region broadens which corresponds to deceleration of the flow. Therefore, the inner radius of the OH-fluorescence at two flame heights was chosen to describe the local response behavior of the flame front. The maximum OH-intensity is localized at the flame front and shows a displacement when the electric field is applied. Hence, the inner radius was calculated as half maximum of the slope from the extracted profiles.

The results show a similar behavior of the flame radius for frequencies of 1 and 10 Hz. First changes occurred 4 ms after the rising and the falling edge whereas first flow decelerations were measured already after 2 ms at the flame root. After the first response flame oscillations appear and it takes more than 20 ms to reach stationary conditions. From the delay between the two observed heights the travelling speed of the disturbance through the flame front was calculated to be 2.5 m/s which correspond to the convective velocity. For higher frequencies the duration where the electric field is applied is too short to reach stationary conditions. Therefore, the transient phenomenon establishes a quasi-stationary condition with an oscillating character. The oscillations are phase shifted at 5 and 1.5 mm for 100 Hz and the amplitude especially at 15 mm is larger than for lower frequencies. Therefore, it is assumed that the flow processes interfere with each other. The region of deceleration reaches until 100 Hz its maximum strength of about 1.1 m/s and reveals a similar behavior. The deceleration grows from the flame root expanding downstream as long as the electric field is active. After the deactivation the deceleration reduced and the flow is also accelerated due to the slow flame response. At 200 Hz the amplitude of the radius oscillation is smaller and in phase again. The response times especially at the flame root which is essential for active flame stabilization by electric fields were estimated to be about 2-4 ms, which is faster than theoretical values provided in the literature for the integral flame. However, no clear indication or negation for changed flame chemistry could be detected. Therefore, this effect needs further analysis focusing on the temperature and species field by application of additional measurement techniques.

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