FAST FLAME CONTROL BY NANOSECOND BARRIER DISCHARGE

A. V. Krasnochub, E. I. Mintoussov, A. A. Nikipelov, S. M. Starikovskaya, A. Yu. Starikovskii

Physics of Non-Equilibrium Systems Laboratory, Moscow Institute of Physics and Technology, Moscow, Russia

In this paper the study of the pulsed nanosecond barrier discharge influence on flame blow-off velocity was performed. It was found that proper organization of discharge is crucial for effective flame control. It's necessary to provide the production of OH radicals in a certain place of the flame for maximum effect. The main characteristics of successful energy input, in this case, is the maximum value of the ratio of flame blow-off velocity with discharge to that one without discharge (instead of maximum possible flow speed), and the minimal ratio between discharge energy input and chemical power of a burner.

Three different quartz nozzles of rectangular cross-section with 2.2, 2.5 and 4.3 mm in width and the same length of 30 mm were used. A stainless steel 0.8 mm thick high-voltage electrode was placed inside the nozzle and grounded electrodes were set tightly into quartz tubes and placed near the nozzle edges parallel to them. In the present work we used three different types of nanosecond pulses: with FWHM 7, 19 and 24 ns. The voltage on the discharge gap could be 14 kV or 22 kV, the pulse polarity was positive. A pulse repetition rate could be varied within the range of 400-1000Hz.

To investigate the formation of OH radicals by nanosecond discharge we have adjusted the laser induced fluorescence technique. The experimental setup and details of adjustment procedure are presented in Fig.1 (a, b). Laser emission at 281 nm was used to obtain fluorescence of OH. The emission was produced by the laser system concerning NdYAG laser at second harmonics and a dye laser with a doubling system. A system with cylindrical lenses was used to get a 2D map of fluorescence. A laser wavelength was adjusted with the help of simultaneous registration of laser wavelength and rotational system of OH emission from propane-air premixed flame (typical plot used for adjustment is demonstrated in Fig.1a). The fluorescence was registered by a PicoStar HR12 (La Vision) ICCD camera with an interference filter (315 nm with the width of 1.8 nm at the half-height). The camera gate was 30 ns. The camera was synchronized with NdYAG laser operation.

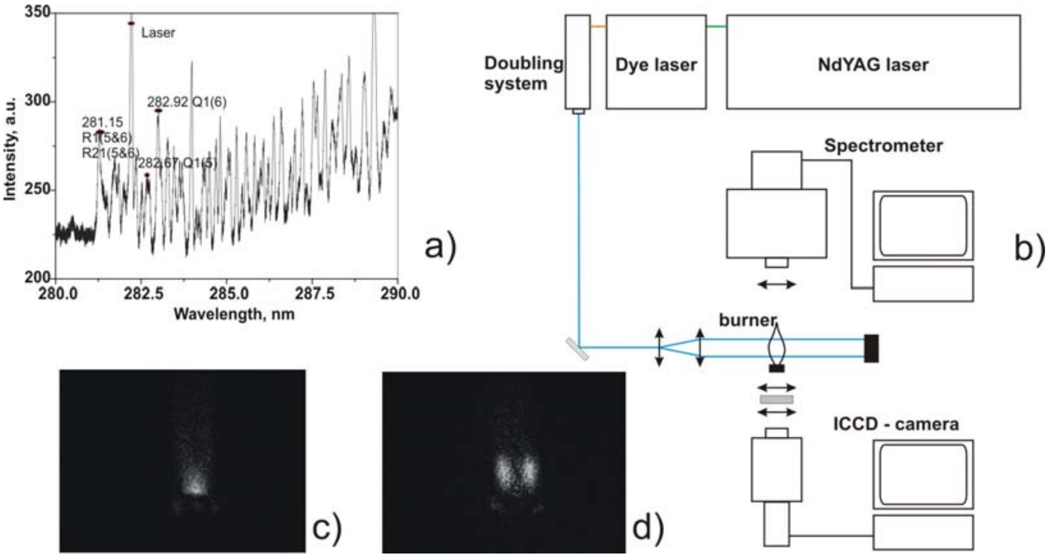

Fig 1: a) – spectrum of OH emission from the burner with superposed laser emission; b) – scheme of the experimental installation; c) – typical OH* emission from propane-air premixed flame; d) OH LIF-image at the same experimental conditions

Comparison of OH* emission (obtained with the same interference filter) from the burner and 2D OH fluorescence (Fig.1b and 1c, respectively) demonstrates a significant difference in a spatial distribution of excited OH radicals and OH in the ground state even in the absence of the discharge.

The formation of a secondary OH peak in the discharge zone corresponds to the statement that the place where the active particles are put is important. It's useless to produce radicals in the reaction zone, where temperature is high enough and radical production in discharge is negligible with that one in chain reactions. On the other hand, if radicals are produced before the reaction zone at a large distance, they probably recombine and just heat the gas for a few decades of K. So, an optimal place exists, where radical production is most effective in terms of flame blow-off increase.

So, there are two types of discharge application in combustion problems. The first is to ignite a mixture in areas with a low flow speed, with a combustion rate remaining constant, i.e., by heating, as in [4], and the second is to increase a combustion rate by a uniform treatment of the mixture in the discharge. We think that the second way is more perspective and that's why one should use a relative flame velocity increase as the main parameter of discharge effectiveness, instead of absolute values of flow speed. We should compare the discharge power to the relative burner power increase, taking into account that the completeness of combustion could change. Our results show that the flame propagation velocity can be increased more than twice, depending on the way we organize discharge as well as discharge parameters (duration, pulse repetition rate, voltage, etc). The intensification ratio (blow-off rates ratio with and without discharge) is significantly higher when a greater number of streamers is used. Results for different pulse durations confirm idea about importance of number of active particles which are produced under the discharge action.

An additional proof to the suggested theory and the model of the radical influence lies in the results of experiments with the Ar/O2/C3H8 mixture. According to this theory ([1]), the main channel of active particles production (O, H, OH) in the nitrogen/oxygen mixture is the following:

- Nitrogen excitation by electronic impact with the production of electronically-excited molecules.
- Kinetic of excited states, primarily quenching of excited nitrogen on oxygen molecules with the atomic oxygen formation.
- Combustion of a new mixture with highly non-equilibrium radicals concentration and production of new radicals (OH).

So, in experiment we have changed the nitrogen in the mixture to argon in order to remove the main channel of active particles formation and decelerate the flame in comparison with the N2/O2/C3H8 mixture. Indeed, the results of experiments showed that the phenomenon in the argon mixture is much weaker. This is an evidence for our flame acceleration model.

References

[1] Mintoussov E.I., Pancheshnyi S.V., Starikovskii A.Yu.. AIAA paper 2004-1013.

[2] Nudnova M.M., Pancheshnyi S.V., Starikovskii A.Yu. Proceedings of XV International Conference on Gas Discharges and their Applications, Vol.1, p.339-342.

[3] Mintoussov E.I., Starikovskii A.Yu. Proceedings of 16^{th} ISPC, ISPC-455.pdf.

[4] Galley D., Pilla G., Lacoste D., Ducruix S., Lacas F., Veynante D. and Laux C.O. AIAA paper 2005-1195.

[5] Krasnochub A.V., Mintoussov E.I., Nudnova M.M., Starikovskii A.Yu. Interference between streamers in bunch of streamers. XXVIIth ICPIG, 2005.