NON-STATIONARY ELECTRIC FIELD EFFECT ON STABILITY OF A LIFTED DIFFUSION GASEOUS HYDROCARBON FLAME

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Abstract

The results of studying a weak electric field effect (with an intensity vector rotation) on a diffusion combustion of gaseous hydrocarbons are presented. The main attention is paid to investigation of the electric impact on a flame stabilization. A direct high-speed video recording was used, as well as spectrozonal registration of the own flame luminescence (the emission of excited radicals OH* and CH*). It is shown the region of flame stabilization (ignition points) fixes in the horizontal electrodes plane and there is a local intensification of diffusion combustion in the applied electric field. Also the oscillation frequency of the flame stabilization region is determined and the electric field effect damps these fluctuations.

Key words: diffusion flame, lifted flame, electric field, flame stabilization, spectrozonal registration, lift-off height, flame fluctuations

Introduction

The relevance of researches related to a study of hydrocarbon fuels combustion processes in a diffusion mode is undoubted because of a wide application of diffusion burners in technics, as well as the deficit of energy resources associated with their exhaustible and non-renewable.

It is more favorably from a practical point of view when combustion in open burner torch occurs steadily. Depending on a position of a stable combustion zone a diffusion flame can be stabilized both at the edge of the burner nozzle and at some height from it – lifted flame, that is the subject of our study.

The mode of a lifted flame (or "torn off flame") is characterized by the fact that the flame stabilizes in the gas flow at a considerable distance from the burner edge during the turbulent mixing of a pure fuel jet with an oxidant. At the flow boundary a zone of irregular vortices is formed, in which an intensive turbulent mixing of the initial mixture with the surrounding atmosphere occurs, and flow velocity decreases. The gas velocity and the burning rate of the resulting combustible mixture (corresponding to the turbulent flow) are compared at some distance from the burner nozzle, and the flame stabilizes.

The disorder and randomness of the turbulent motion causes the flame front to fluctuate near an equilibrium position, which becomes more significant for flames stabilized downstream.

The stability characteristics mean the conditions of detaching and attaching of the flame, its blowout, as well as, a lift-off height, an amplitude and a frequency of oscillations near the average flame lift-off height.

Electric properties of a flame

The high concentration of charged particles (10^9-10^{12} cm^{-3}) in the flame of gaseous hydrocarbons [1], caused by the chemoionization mechanism, allows it to be influenced by an external electric field, in particular for organization of the most efficient and optimal combustion process.

There are three main mechanisms for the effect of an electric field on combustion processes: electro-gas-dynamic – the appearance of mass forces acting on a neutral gas and causing a redistribution of gas-dynamic flow parameters, thermal – the Joule dissipation of the electric field energy, kinetic –a direct action of an electric field on the kinetics of chemical combustion reactions.

The effect of a weak (sub-breakdown intensity magnitude) external electric field on the flame is determined mainly by the electro-gas-dynamic effect, which makes it possible to change the rate of mixture formation and many integral characteristics of the flame. This effect – "ionic wind" – takes place due to the inequality of the electric forces acting to the sides of the electrodes, which is associated with a different voltage drop in the regions of the inter-electrode space: because of the small mobility of ions, the main voltage drop occurs in a positively charged region [1].

So when the charged particles of a flame move in an electric field, the energy is transferred to the neutral gas. Thus, due to the "mechanical movement of gas", it is possible to change the surface and shape of the flame, the speed of its propagation and the combustion process of the fuel [2].

Scheme of the experiment

The effect of a non-stationary weak electric field on a lifted diffusion flame of gaseous hydrocarbons (methane, domestic propane) was considered at Re numbers at the nozzle outlet are from 1100 to 6500 (the nozzle diameter for propane d_p=1 mm and for methane d_m=1.5 mm). The fuel delivery and flow control were performed by the Bronkhorst El-FLOW Select mass flow regulator.

The including 8 thin stainless steel electrodes (their diameter 1 mm) with their possibility of height (*h*) adjustment scheme was developed and created (Fig. 1) for the non-stationary electric field effect on the flame.

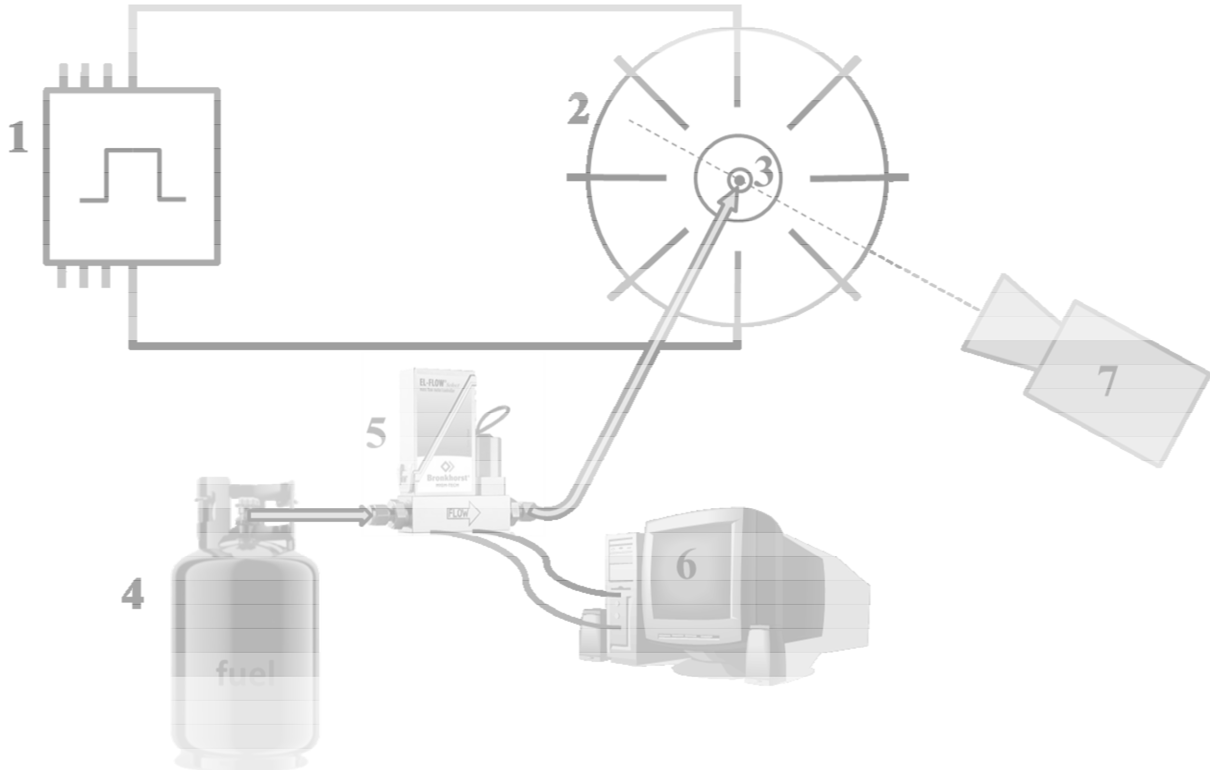


Figure 1. The experimental scheme: 1 - power supply+ electronic pulse switch, 2 – electrodes (8 pieces), 3 – diffusion burner nozzle, 4 – fuel balloon (propane or methane), 5 – flow regulator, 6 – computer, 7 – camera (Imager Intense CCD,

High Speed Star3); *the connection of one electrodes pair is depicted, the rest of them are connected by analogy

A voltage is applied to a pair of opposite electrodes and switched around by the electronic pulse switch (specially designed for the presented studies and created by a third-party organization), thereby creating the rotation of the electric field intensity vector relative to the fuel jet axis. The experiments were carried out when the rotation frequency is about 7 Hz.

The flame behavior was registered by using the LaVision High Speed Star 3 и Imager intense CCD cameras. Interference filters (CH* (430 nm) and OH* (307 nm)) were used in conjunction with the Imager intense CCD camera to obtain spectrozonal pictures. Processing of the obtained images was performed in the software DaVis (LaVision).

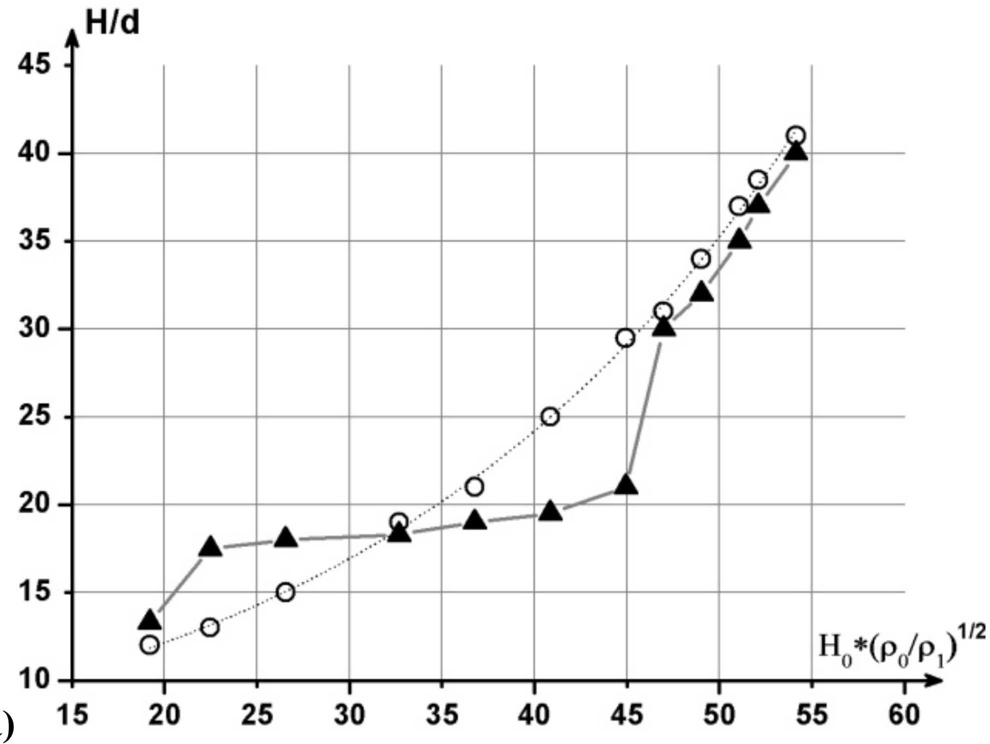
Results

In the mode of a lifted diffusion flame of gaseous hydrocarbons increasing of the fuel outflow rate leads to increasing of the lift-off height of the flame – the stabilization region (points of ignition) – above the nozzle edge. With the further increase of the flow, it leads to a flame blowout.

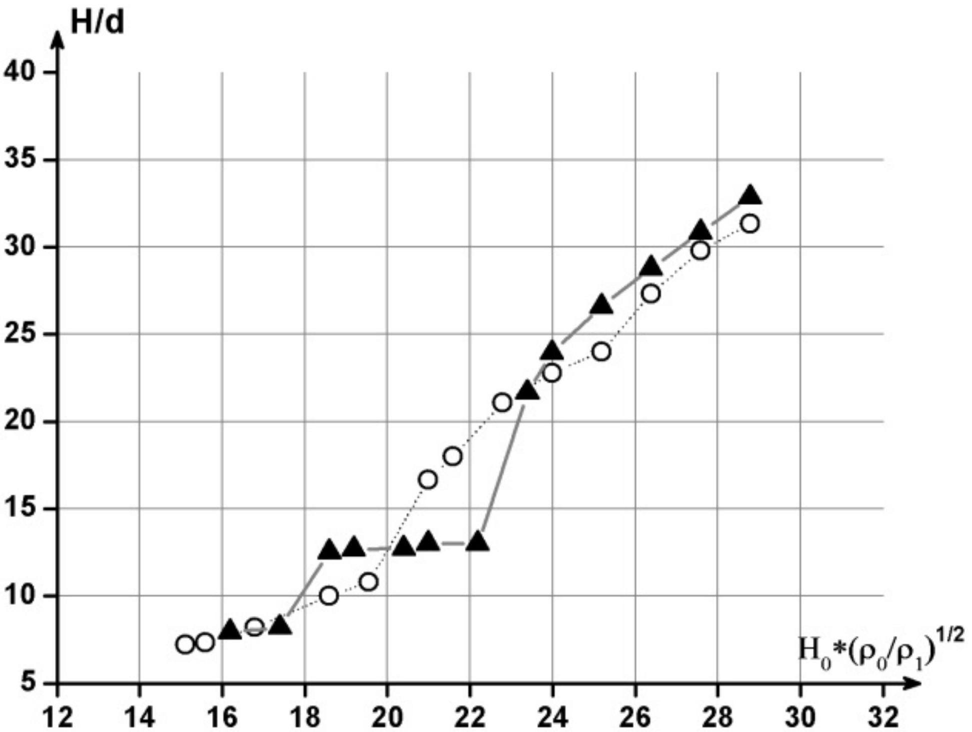
The experiments with the lifted diffusion flame of propane and methane results showed that in the electric field with rotation of the intensity vector (magnitude is 1000 V/cm, rotation frequency is 7 Hz), the points of ignition (the flame base) are shifted to a horizontal electrodes plane and fixed in this region (or slightly above it - for increased, heightened fuel consumption) during the impact period.

The fixed position of the flame base remains when the fuel flow rate varies over a wide range (from 30% to 60% of the velocity range for the existence of the regime of the lifted flame). In this case the expansion of the flame base is observed, indicating the intensification of the mixing processes and the increase in an effective burning surface, which, of course, leads to the intensification of combustion confirmed by the results of spectrozonal photography.

The plot of the dimensionless propane and methane flames lift-off height above the nozzle edge as a function of the homochronism criterion H_0 was obtained when using the electric field and without it (Fig. 2).



a)



b)

Figure 2. The dependence of the dimensionless lift-off flame height on the homochronism criterion H_o and the ratio of the fuel (ρ_f) and oxidizer (ρ_o) densities: (a) propane, (b) methane, where: ○ - without the electric field, ▲ - with the electric field effect

In describing diffusion flames of many combustible gases a dimensionless distance from a nozzle edge up to a stabilization height is given by the functional relationship:

$$\frac{H}{d} = f\left(\frac{\rho_f}{\rho_o}, H_0\right)$$

where ρ_f – a fuel density, ρ_o – an oxidizer density and H_0 – the homochronism criterion (2), which represents the ratio of characteristic burning time τ_{burn} and flow time τ_{flow} [3]:

$$H_0 = \frac{u_0 \tau_{burn}}{d} = \frac{\tau_{burn}}{\tau_{flow}}$$

On the plots of Fig. 2 there is the horizontal section, indicating the flame stabilization in the plane of the electrodes (or near it) at the height h (for propane h =17 mm, for methane h =18 mm) under the influence of the non-stationary electric field. In addition when the electric field is applied to the flame, it is possible to increase the fuel consumption above the maximum possible for the existence of the lifted flame. Without the external electric field impact a flame blowout observed at such consumptions.

Using Imager Intense CCD (LaVision) camera and interference filters, the spectrozonal recording of the own emission of a propane flame at the wavelengths of excited CH* and OH* radicals was carried out. An analysis of the data obtained showed that under the electric field effect with the rotation of the intensity vector the intensity of radiation of the excited CH* and OH* radicals increases (Fig. 3).

The data presented in the Fig. 3 indicate the intensification of combustion process when the non-stationary electric field effects. For propane combustion the CH* radical emission intensity distribution is in proportion to the heat release rate [4], which integral represents the completeness of combustion along the flame height.

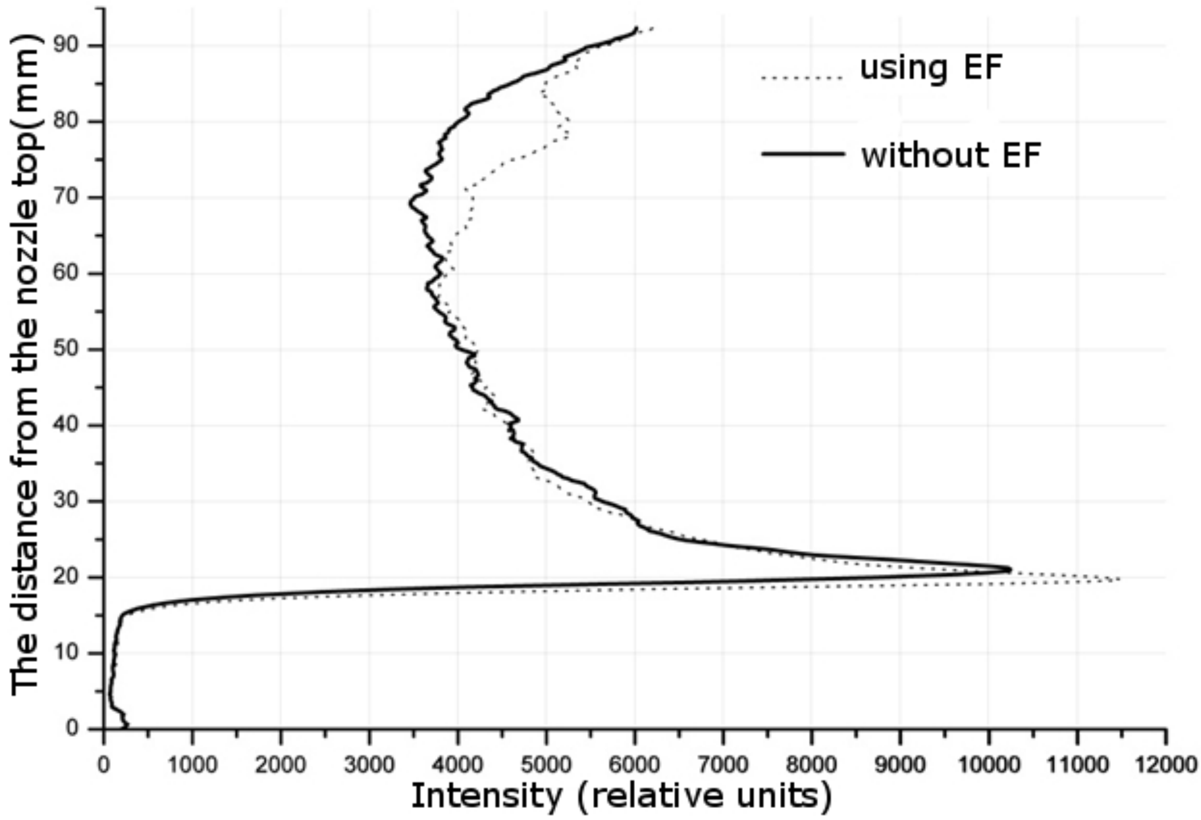


Figure 3. The emission intensity CH* radical distribution along the propane flame height (propane flow velocity is 18 m/s, EF is the electric field)

Instant photographs of a lifted diffusion flame of methane obtained using the camera High Speed Star 3 (LaVision) allowed determining the average amplitude of fluctuations of the points of ignition (flame base), which at Re=3480 was 1.5 mm (1% of the average lift-off height). It is established that a non-stationary electric field with intensity 860 V/cm effect on a flame leads to twice decrease the fluctuation amplitude of the ignition points. Fourier analysis of the lift-off height values of the methane flame (Re = 3480) obtained under the influence of a non-stationary electric field and without it was performed. The characteristic frequency of oscillation of the ignition points is determined as about 3 Hz. It is partially consistent with the experimental data of the authors [3], who, in addition to this frequency, also detected higher frequencies of 35-55 Hz. Due to the stabilizing effect, periodic oscillations are not observed in the electric field.

Conclusions

For the lifted diffusion flame the oscillation frequency of the stabilization region is determined. The superposition of a weak non-stationary electric field – with the intensity vector rotation – allows stabilizing the lifted diffusion flame in the electrodes plane, reducing the amplitude of the oscillations of the flame leading edge substantially and intensifying the combustion process in the stabilization region. In addition, it was found that at high methane consumption the flame stabilization by the electric field occurs with a delay, after some "induction period".

References

1. **J. Lawton, F.J. Weinberg**. Electrical aspects of combustion. Clarendon press. Oxford, 1969.
2. **E.M. Stepanov, B.G. Dyachkov**. Ionizatsiya v plameni i elektricheskoe pole. Flame Ionization and the Electric Field. Metallurgy, 1968.
3. **V.K. Baev, V.A. Yasakov**. Issledovaniye ustoychivosti diffuzionnogo plameni // Izv. Sib. Otd. Akad. Nauk SSSR, Ser. Tekh. Nauk. – 1969. – V. 3, # 1. – P. 38-42.
4. **M. Orain, Y. Hardalupas**. Effect of fuel type on equivalence ratio measurements using chemiluminescence in premixed flames // Comptes Rendus Mécanique. – 2010. – V. 338, # 5. – P. 241-254.

Nomenclature list

h – height of electrodes,

H – flame lift-off height,

H_0 – homochronism criterion,

ρ_f – fuel density,

ρ_o – oxidizer density,

d – nozzle diameter,

d_p – nozzle diameter for propane,

d_m – nozzle diameter for methane,

u_0 – flow rate,

τ_{burn} – characteristic burning time,

τ_{flow} – characteristic flow time,

EF – Electric Field