Pulsating combustion of the propane-butane mixture with air and gas ionization in a tube

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Abstract. While an ionization during laminar or turbulent combustion has been studied quite well, the ionization processes in pulsating combustion of gases not so well known. In this paper, pulsating combustion of propane-butane mixture with air and gas ionization in the vortex chamber is considered.

1. Introduction
It is known that the oscillations of gases in the combustion chamber considerably accelerate the combustion process and processes of heat and mass transfer [1, 2].

The main mechanisms of ionization with uniform combustion are thermal and chemical ionization. Thermal ionization has a negligible effect but in the mode of pulsating combustion, the effect of thermal ionization is higher. Major ions formed during the combustion of a mixture of propane-butane-air used in the experiment are \( \text{C}_3\text{H}_3^+ \), \( \text{C}_2\text{H}_5^+ \), \( \text{H}_3\text{O}^+ \), \( \text{C}_4\text{H}_5^+ \), \( \text{C}_3\text{H}_6^+ \), \( \text{C}_4\text{H}_7^+ \), \( \text{C}_5\text{H}_8^+ \), \( \text{HO}_2^+ \), \( \text{C}_6\text{H}_7^+ \), \( \text{C}_7\text{H}_{11}^+ \), \( \text{C}_8\text{H}_{13}^+ \). In the uniform combustion mode, the average electron energy in the chemiluminescent zone reaches 1 eV, the maximum energy is 2-2.5 eV [3, 4]. The fuel-air ratio has a significant effect on the ion concentration. In the transition from uniform combustion mode in unlimited volume to a pulsating mode, an increase in the number of radicals is observed [5].

Studies have shown that the magnitude of the ion current, as well as the flame propagation velocity increases with increasing air excess coefficient, the maxima of these values is observed when the air excess coefficient tends to 1. Accordingly, the ion current has bigger values in non-equilibrium combustion modes, such as turbulent and pulsation modes, compared to laminar ones. Unlike to the turbulent mode, in the pulsation combustion mode, the spatial-temporal distribution of ions is observed, due to the influence of acoustic oscillations on the flow [6].

The purpose of this work is to estimate the degree of gas ionization in the pulsating combustion mode and to determine the spatial and temporal distribution of ions depending on the fuel-air ratio and acoustic oscillations.

2. Experimental setup
An experiment to determine the degree of ionization in the pulsating combustion mode was carried out in a laboratory setup with a vortex chamber of pulsating combustion (figure 1). A mixture of propane-butane and air was used as fuel, which was premixed and fed to the burner through four tangential nozzles. Chromatographic analysis of the mixture composition showed that the fuel consists of
propane (74.35%), methane (5.2%), isobutane (8.77%) and butane (6.9%). The fuel mixture is ignited by the spark igniter. The combustion chamber is a cylinder that can be divided into two areas. From the lower closed part of the chamber to the point of junction of the nozzles, a “chamber of supplying the combustible mixture” is formed. The lower part is closed by a regulating piston, which changes the volume of this chamber. The second area is the burning zone (swirling pulsating flame). Outside the chamber there was a water cooling (9) of a hollow copper tube, which prevents overheating and destruction of the nozzles.

The degree of ionization was determined by a passive ionization probe (12), which is a tungsten electrode in ceramic insulation. The measuring part of the probe is a bare part of tungsten wire (up to 1 mm) located outside the ceramic tube. The probe was placed in the measurement area through the open end of the burner. The signal from the probe was taken with an Rigol DS2072A oscillograph, in which the recorder mode voltage changes in several parameters (maximum ($V_{\text{max}}$) and minimum ($V_{\text{min}}$) values, peak-point voltage ($V_{\text{pp}}$)) were recorded. These parameters were recorded on a USB-drive for further processing on a computer using the Origin software and MS Excel software.

The zone of spatiotemporal distribution of ions is located throughout the working volume of the burner. This zone is formed due to the swirling of the flow with tangential nozzles, pulsating combustion mode, as a result of which the resulting acoustic oscillations and uneven recombination of the reaction products.

3. Results

In the developed vortex chamber of pulsation combustion, oscillations of gas with a frequency of 258 Hz and 773 Hz are pronounced. This corresponds to the first and third harmonics of the pipe, closed at the entrance and open at the exit, with the optimum ratio of the air-fuel mixture. The optimum mode for a laboratory installation of pulsation combustion is 0.996 l/min for propane-butane and 24 l/min for air. Excess air coefficient make 1.03. This corresponds to the calculated stoichiometric ratio of 1 to 23.34 for the complete combustion of the existing mixture of propane-butane and air.

The maximum temperature of the flame flow was fixed near the burner wall at a distance of 3 mm from the regulating piston and amounted to 1752 °C. The temperature distribution of the reaction products was measured (figure 2). In the future, the calculated combustion temperature of the fuel mixture will be adopted. As in the pulsating mode, a heat transfer to the pipe wall increases.
During the experiment, it was found that at the optimal fuel-air ratio in the pulsation mode, higher values of the degree of ionization were recorded than in the laminar mode. The highest value is observed in the zone of maximum temperature, 4 mm from the regulating piston, peak-point voltage up to 400 mV, with a shift towards a positive charge of 200 mV, negative charge -200 mV (figure 3).

The complexity of temperature distribution along the height of the burner and its radius, as well as the imposition of odd harmonics to the main harmonic, determines a complexity of a behavior ionization distribution.
4. Conclusion
The developed vortex chamber of pulsation combustion meets the requirements for the experiment on measuring the degree of ionization and determining the spatiotemporal distribution of ions.

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