Distribution of electric potential during pulsating combustion of a propane-butane fuel mixture with air in a vortex combustion chamber

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Abstract. Currently, research on pulsating combustion regimes, in particular, control methods, remains relevant. Pulsating combustion mode has its own electric field created due to the ionization of the combustion products and is characterized by oscillatory processes of the combustion zone. In this work is to assess the effect of acoustic gas vibrations on the distribution of electric potential and its amplitude-frequency characteristics.

1. Introduction
At present, the world is an acute issue of waste disposal. One common way is burning. To minimize atmospheric emissions, vortex combustion chambers are widely used in industry. It is known that the initiation of thermoacoustic oscillations significantly shortens the processes of combustion and heat and mass transfer in combustion chambers [1, 2]. The combustion process of hydrocarbon fuels is accompanied by ionization of gases. Studies have shown that the flame propagation velocity, as well as the ion current increases with increasing excess air coefficient, the maxima of these values are observed when the excess air coefficient tends to 1. The transition from uniform combustion of a mixture of propane-butane and air in an open volume to pulsating the regime is characterized by an increase in the number of radicals and, consequently, an increase in the degree of ionization [3]. It was previously established that the pulsating combustion mode has its own electric field created due to the ionization of the combustion products and is characterized by oscillatory processes of the combustion zone [2, 4]. Further study of the properties of pulsating combustion and gas ionization, aimed at finding methods that ensure strong interaction of the above processes, is an urgent topic for ecology and energy [5].

The purpose of the work is to assess the effect of acoustic gas vibrations on the distribution of electric potential and its amplitude-frequency characteristics.

2. Experimental setup
To solve this aim, an experimental setup for pulsating combustion with a vortex combustion chamber was developed. The experimental setup consists of a gas outlet pipe and a chamber equipped with a control piston and four tangential central gas port with nozzles through which fuel is supplied [5]. A propane-butane mixture is used as fuel. Chromatographic analysis of the composition showed that the fuel consists of propane (74.37%), methane (5.2%), isobutane (8.77%), butane (6.9%), hydrogen sulfide (4.13%) and water (0.63%).
In the experiments, gas vibrations were observed at the natural frequency in the range 246–264 Hz, as well as higher harmonics. For an experimental setup, a conservative analogue system is a pipe with a rigid partition at one end and open at the other end - a quarter-wave resonator. However, due to the presence of nozzles for supplying fuel near the closed end of the pipe, the system may exhibit the properties of a half-wave resonator (pipe open at both ends).

An experiment to measure the electric potential in the flame of a pulsating combustion vortex chamber was carried out with an air excess coefficient close to 1. The optimal range of the fuel to air ratio was 1 L/min to 23.5 L/min, respectively. To measure the potential, a passive single probe was used, which is a tungsten-rhenium wire in ceramic insulation. The measuring part of the probe is a non-insulated piece of wire (length 1 mm, diameter 0.5 mm) of a cylindrical shape located outside the ceramic tube. The probe could move along the axis of the pipe. The signal from the probe was taken with a Rigol DS2072A oscilloscope and recorded on a USB drive for further processing on a computer using Origin software and MS Excel. To measure sound pressure inside the combustion chamber, the unit is equipped with a plug-in acoustic probe. This device is designed to measure sound pressure in a small volume of the combustion chamber, as well as near a source of acoustic vibrations - a vortex pulsating flame.

3. Results

It was found that gas vibrations lead to a spatio-temporal distribution of the potential and, as a consequence, the charge in the combustion region of the fuel and oxidizer. In a fixed section of the combustion zone there are constant $U_0$ and variable $U_a$ components of the potential difference between the probe and the wall of the combustion chamber (Figure 1).

![Figure 1](image.jpg)

**Figure 1.** Distribution of the constant and variable components of the potential difference between the probe and the wall along the combustion chamber.

The range of the oscillations potential depends on the axial coordinate. It was found that these oscillations occur at the natural frequency of acoustic gas vibrations. The natural frequency of acoustic gas vibrations is 252 Hz and is close to the main frequency of the electric potential oscillations 250 Hz (Figure 2). This indicates the synchronization of pulsating combustion and ionization processes.
4. Conclusion
So, at the pulsating combustion mode, an electric field arises in the combustion products, the potential of which has constant and variable components.

In the spectrum of acoustic oscillations, the main frequency and higher harmonics corresponding to the quarter-wave resonator are observed [6]. Peaks at even, non-resonant harmonics are not due to the ideality of the quarter-wave resonator, due to the presence of nozzles for supplying the fuel mixture near the closed end of the pipe.

The dependence of the amplitudes electric potential oscillations at higher harmonics on the amplitudes of acoustic vibrations at the corresponding harmonics is non-linear. Apparently, the electric potential oscillations are quite sensitive to the frequency of acoustic oscillations, which explains the lower amplitude of oscillations at the third harmonic as compared to the second. At the same time, the amplitude of acoustic oscillations at the third harmonic is the resonant frequency and significantly exceeds amplitude at the second harmonic.

Thus, acoustic oscillations act directly on the charged component of the combustion products, thereby modulating the electrical potential of the system. Moreover, using the example of higher harmonics, the effectiveness of the influence of acoustic oscillations on the fluctuations of the electric potential is highly dependent on the frequency.

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