Development of the setup for study of the gas ionization in the pulsating mode of combustion

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Abstract. At present, known methods of direct conversion of the chemical energy of gaseous fuels to electrical energy are not so effective. This work is directed to developing the setup for experimental study of the gas ionization processes in the pulsating mode of combustion. This problem being solve for the first time. As result, schematic diagram and methodological recommendations will be developed which will be subsequently used for experimental studies.

1. Introduction

It is known that ionization of the gas begins at sufficiently high temperatures, for example, at the combustion temperature of the gaseous fuel. In a magnetic field, moving electric charges are separated and can be concentrated at electrode surfaces located in the combustion zone. This principle used in magnetohydrodynamic (MHD) generators - power plants in which working medium energy, moving in a magnetic field, is converted directly into electrical energy. In such devices, liquid or gaseous electrically conductive media can be used as a working fluid.

At the present time, development of methods for intensification of the ionization processes in burning gases is being carried out with the aim of increasing an efficiency of direct conversion of the organic fuels energy into electric energy. Many developments in the MHD energy generation field used technologies with pulsating conductive medium in a channel, creating regions of spatial distribution of various characteristics of working fluid, synchronizing the flow oscillations with alternating magnetic field. As example, there is an MHD generator in which a high-temperature gas injected into a closed toroidal channel in such way, that the gas flow moves along a circular channel and form of clear number of alternating high and low-pressure regions [1]. There is directly converting method of pulsating detonation combustion fuel energy into electrical energy by feeding portions of the fuel mixture to two counter directed detonation combustion chambers. The ignition and detonation combustion of the fuel creates a shock wave that moves back and forth in the working channel. The wave carries a positive space charge, which is created by excluding electrons from the combustion chambers by assistance of a catalytic electrode and electromagnetic induction. Electromagnetic field is induced by windings of magnetic contour that enfold the working channel. The useful alternating current voltage is consumed from the catalytic electrode [2]. When vortex burners operate in acoustic resonators, the energy of combustion of the fuel is converted into the vibrational energy of the exhaust gases. There are theoretical studies of conducting fluid oscillations in converters of acoustic energy into electrical energy, which is applicable to pulsating MHD generators [3].
The above examples allow us to consider that the development of effective methods for direct conversion the combustion energy of fuel into electric energy is an actual problem. In this project it is proposed to use the pulsed combustion mode, in which self-excitation of acoustic oscillations intensifies the process of ionization of burnt gases [4, 5]. This is due with the burning regime, in which the flame periodically changes its shape and size. Simultaneously with the same frequency, all process parameters in a combustion chamber and at different points of the path oscillate with the same frequency: pressure, gas velocity, mixture composition, temperature, etc. [6]. It is proposed to impact to an ionized gas with constant and alternating magnetic fields. At present the processes of the gas ionization in the pulse combustors, where acoustic oscillations are synchronized with alternating magnetic field, are investigated insufficiently.

The purpose of this work is the rationale and development of the schematic diagram of the experimental setup for experimental study of gas ionization processes in pulsating mode combustion of the fuels under influence a constant and alternating magnetic fields.

2. Prehistory of the research.

In study of interactions between electric discharges and acoustic oscillations, under turbulent combustion mode of gaseous fuels, it was found the space-time distribution of ions in acoustic field occurs [7,8]. In this work were used two types of burners with tangential feeding of a gas mixture into a combustion chamber (Figure 1). First burner was a tube with one nozzle and an electrode placed in the center. In the operation of single nozzle burner, acoustic oscillations didn't excited, but nevertheless, an electric potential of direct current was induced on the probe, which varied depending on stoichiometry of the fuel mixture composition. A direction of the electric potential depended on the stoichiometry of premixed fuel supply and varied from -800 to +990 mV. When a mixture were lean, with an excess air ratio of $\alpha = 1.37$, the voltage was 990 mV. With a rich mixture, with an excess air ratio $\alpha = 0.8$, the voltage at the probe was minus 800 mV (Figure 2).

![Figure 1. Scheme of burners.](image)

Burner with a single nozzle was excited acoustic oscillations not so well. Therefore a second burner with three nozzles was made. In this burner, acoustic vibrations were excited in a wide stoichiometric range. As in the first burner, three nozzles burner has similar central electrode. The second electrode was the combustion chamber body itself. During steady-state burning on probe electrode inducted constant voltage. During transition to the pulsating combustion mode, a voltage had been becoming alternate and also depends on stoichiometry.
The three nozzles burner combusted in pulsating mode in the wide stoichiometric range. At appropriate temperature, the oscillation frequency was equal to 400 Hz, as like as the resonance frequency of the combustion chamber. An amplitude of oscillations potential at the central electrode also depended on stoichiometry. For $\alpha = 1.2$, the amplitude of the oscillations was about 1000 mV (marked as red line, Figure 2). Figure 3 shows the oscillogram of signal from the probe at a stoichiometry for $\alpha = 1.4$. The frequency of oscillations in this mode was equal to main acoustic resonance of the tube (the first harmonic).

These experiments prove that during operation of swirl burners in turbulent and pulsating modes, the space-time distribution of ions take place. Moreover, during operation of swirl burners in the pulsating mode powerful acoustic waves arise with a power level up to 140 dB, and the processes of ionization of burnt gases become intensely.
3. Experimental setup.
The observed phenomena prompted us to create an experimental setup to study hydrocarbon fuel combustion in pulsating mode for space-time distribution of ionization. Schematic diagram of experimental setup is shown in Figure 4.

![Schematic diagram of the experimental setup](image)

1. Fuel gas capsule
2. Air compressor
3. Control valves
4. Manometer
5. Gas flow meters
6. Gas mixture
7. Gas mixture splitter
8. Nozzles
9. Piston
10. Spark igniter
11. Burner body
12. Ionization probe
13. Electrodes
14. Ring magnet
15. 3D static

Laboratory setup is based on a swirl burner (Figure 5). The burner body has tangential nozzles through which the prepared combustible mixture was supplied. Gas-air mixture ignition plug was installed in the swirling area. At the lower part of burner body was closely fitted piston. The piston was needed to fine retune pulsation combustion mode. In addition to the piston, it is possible adjusting tube length to change resonant frequencies. Additional advantages of the solution are an ability using other materials or designs of tubes.
A ring magnet or electromagnet is placed along the burner body on the movable stand. They will create permanent or alternating magnetic fields. A movable stand will to accurately position magnets relative to an ionization zones. Measurement of a distribution and maximum ionization zones will be carried out by ionization sensor that place inside the burner. A special sensor's stand will be designed for allowing placed it in all three dimensions (3D stative). It is necessary to study distribution zones of light or heavy ions, not only along the vertical axe of the burner in the combustion zone, but also for determining of the concentration zones of the positive and negative ions in near-wall layers. Standing waves excited during a pulsating combustion mode, can effect on plasma quasineutrality. Presumably, there will be zones of quasineutrality disturbance observed in the combustion tube. As result, ions formation depends on not only charge potential, but also on distribution nodes and antinodes at standing waves.

4. Conclusion
Thus, a schematic diagram of the pulsating combustor has been developed to study gas ionization processes in a magnetic fields. This scheme and recommendations will be used for further research.

Acknowledgements
The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University. The reported research was funded by Russian Foundation for Basic Research and the government of the region of the Russian Federation, grant № 18-48-16005118.

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