Pulsating combustion of propane-butane fuel mixture with air in a vortex combustion chamber

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Abstract. In this paper pulsating combustion of a pre-mixed propane-butane fuel with air in a vortex combustion chamber is considered. In view of the insufficiency of information about the reasons of self-oscillations, it is necessary to determine the gas-dynamic, physical and chemical parameters that cause oscillations of the heat release rate in the vortex combustion chambers.

1. Introduction
There are a lot of works on a topic of the stability of combustion process in the premixed combustion gas turbine engines [1, 2]. In such devices, the mixture of fuel and air burns in a rotating stream. Currently, no consensus on what causes the self-oscillation of gas in the combustion chambers of such engines. Available experimental data do not make it possible to determine the gas-dynamic and physical and chemical parameters that cause the pulsations of the heat release rate. Thus, further studies of pulsating combustion in combustion chambers with rotating flames are needed. In this work, we study the combustion of a pre-mixed propane-butane fuel with air in a vortex combustion chamber [3, 4]. The flame rotates due to the tangential flow of the mixture. The purpose of this work is to analyze the boundaries of combustion stability and to determine the frequency and amplitude of gas oscillations in a vortex combustion chamber.

2. Experimental setup
The combustion chamber consists of a cylindrical pipe and an inlet chamber, the volume of which depends on the position of the piston. For a more uniform distribution of the mixture along the perimeter of the combustion chamber, four nozzles are used (located as shown in Figure 1). The inlet of the combustion chamber is water cooled. The experiments were carried out with a chamber volume of 418 cm³, the height of the working zone from the piston to the exit was 46 cm, the internal diameter of the fuel delivered nozzle was 3.5 mm.

We measured the sound pressure inside the combustion chamber, with a plug-in probe microphone. 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. The probe has a thin tube 15 cm long and 3 mm in diameter. A coil tube filled with sound-absorbing material is placed at the external end of the tube to avoid the reflections of sound waves from the end of the tube.
measuring microphone is located at the side of the tube behind the sound-absorber. We measured the temperature along the axis and along the walls of the combustion chamber by placing a tungsten-rhenium thermocouple (type A) in the combustion chamber; the signal was recorded with a F266 digital device. The received data were processed using software on a PC.

Figure 1. Experimental setup scheme: 1 – upstream chamber, 2 – closed-loop cooling water; 3 – control piston, 4 – nozzle; 5 – circular pipe; 6 – the location of the nozzles for supplying the fuel-air mixture to the setup; 7 – air-fuel supply; 8 – refrigerant charge; 9 – refrigerant outlet; 10 – acoustic probe; 11 – microphone; 12 – deadener filled silicone tube; 13 – computer; 14 – tungsten-rhenium thermocouple; 15 – cold junction; 16 – digital temperature meter F266

3. Results
The approbation of the installation was carried out at constant fuel consumption of 1 L/min. It was found that the self-excitation of gas oscillations in the combustion chamber appear when the air flow varies from 17.5 L/min to 28 L/min. The chromatographic analysis of propane – butane fuel is as follows: 74.37% - propane, 5.2% - methane, 8.77% - isobutane, 6.9% - butane, 4.13% - hydrogen sulfide and 0.63% - water. Since the composition of the fuel is known, we can calculate the coefficient of excess air ratio \( \alpha \) using known relations. Optimal stoichiometric combustion \( \alpha = 1 \) corresponds to an air flow rate of 23.49 L/min. The gas oscillation frequency changed from 246 Hz to 264 Hz depending on the air flow rate and reached it’s maximum at \( \alpha = 1 \). Such an approach does not allow us to unambiguously estimate the effect of the fuel composition on the parameters of gas oscillations. If the air flow rate is variable, this affects not only \( \alpha \), but also the flow rate of the mixture, which affects the fuel combustion and the gas flow in the combustion chamber.

The following measurements were made for fixed air flow rates. Fuel consumption was variable, but in this case, the flow rate of the mixture changed slightly. The data presented in Figure 2 show that the frequency of gas oscillation is the minimum for the stoichiometric composition of the mixture \( \alpha = 1 \). A decrease or increase in \( \alpha \), that is, an increase or decrease in fuel consumption relative to the stoichiometric value, causes an increase in the oscillation frequency. This result is unexpected. The combustion temperature of the stoichiometric mixture and the speed of sound at the entrance to the combustion chamber have a maximum reading. As is well known, the frequency of acoustic gas oscillations in a pipe is directly proportional to the speed of sound [5, 6]. Therefore, one could expect that at \( \alpha = 1 \) the gas oscillation frequency is maximum. Measurements of the amplitude of pressure
fluctuations at the inlet in the combustion chambers showed (Figure 3) that this parameter, unlike the oscillation frequency, has a maximum value for $\alpha = 1$.

**Figure 2.** The dependence of the frequency of acoustic vibrations on the coefficient of excess air ratio; air-flow rate ($V_0$) fixed.

It is known that the amplitude of gas oscillations during combustion depends on their frequency [5-7]. Suppose there is an inverse effect of the amplitude of the oscillations on their frequency. Fluctuations in gas will accelerate heat transfer coefficient to the walls of the combustion chamber. The cooling of the gas flow in the combustion chamber is greater when the oscillation amplitude is higher. Then the average speed of sound in the combustion chamber and, consequently, the oscillation frequency is reduced. Unfortunately, now there are no experimental data on the effect of the intensity of gas oscillations in the vortex combustion chamber on the average gas temperature and sound velocity.

**Figure 3.** The dependence of the amplitude of acoustic vibrations on the coefficient of excess air ratio; air-flow rate ($V_0$) fixed.
Next, the effect of the mixture flow rate on the frequency and amplitude of gas oscillations was studied, provided that the excess air coefficient is constant. If $\alpha = 1$, an increase in the flow rate of the mixture from 10.2 to 24 L/min causes an increase in the oscillation frequency to a maximum value of 260 Hz (Figure 4). A further change in the flow rate of the mixture to 32 L/min causes a decrease in frequency. The experimental data were approximated by local polynomial regression.

![Figure 4](image)

**Figure 4.** Dependence of the frequency of gas oscillations on fuel-flow rate.

The nature of the dependence of the sound pressure level in the combustion zone on the flow rate of the mixture (Figure 5) is the same as for the oscillation frequency. There is a maximum of 166 dB, which corresponds to the maximum frequency. It is not yet possible to explain this result.

![Figure 5](image)

**Figure 5.** Dependence of the amplitude of gas oscillations on fuel-consumption rate.

4. Conclusion
As the result, data were obtained on the influence of the composition and fuel consumption on the frequency and amplitude of gas oscillations in a vortex pulsating combustion chamber.
To explain the results obtained, it is necessary to continue the study, in particular, to determine the distribution of the speed of sound along the combustion chamber, depending on the coefficient of excess air ratio, flow rate, amplitude of gas oscillations in the combustion zone.

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