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INVESTIGATION OF A PULSATING-COMBUSTION CHAMBER

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The results of experimental investigations of a tangential chamber of pulsating combustion with an aerodynamic valve are discussed. The composition of combustion products, the level of sound pressure, and the temperature field are analyzed.

The prospects for using pulsating-combustion chambers (PCCs) in heat technologies are mainly due to the intensification of heat- and mass-transfer processes and decrease in the release of harmful substances into the environment.

As compared to typical combustion systems, pulsating combustion ensures heat- and mass-transfer rates severalfold higher and combustion of greater intensity (by more than one order of magnitude); the release of nitric oxide decreases by a factor of three, and the thermal efficiency improves significantly [1].

One of the immediate directions in the practical use of PCCs is that of the processes of drying of materials (solutions, dispersed materials, etc.). A pulsating (unsteady) high-temperature gas flow formed by a PCC makes it possible to intensify heat- and mass-transfer processes. Gas pulsations, under certain conditions, lead to an increase in the relative velocity of phase motion and a decrease in the thickness of a diffusion boundary layer.

The gas flow at the outlet from the PCC is characterized by velocity fluctuations that attain ±100 m/sec with a frequency of 50–200 Hz and a level of sound pressure of 130 to 180 dB. The pressure fluctuation in the combustion chamber attains a magnitude of ±10 kPa. Pulsating-combustion chambers can efficiently be employed in the technology of spray drying of solutions and suspensions. In this case, they serve as a spraying device and generator of the heat-transfer agent. The short time of contact of material with the heat-transfer agent makes it possible to dry thermosensitive materials. The use of pulsating combustion improves the energy efficiency of drying units to 70% [1-3].

There are two types of pulsating-combustion chambers: those with mechanical and aerodynamic valves. In chambers of the first type, the valves execute a reciprocating or rotary motion. In this case, a pulsating regime of combustion is produced in the PCC due to a discontinuous air (fuel) supply. The principle of operation of these chambers and their design are presented in [1-3] in greater detail.

It should be noted that in the chambers with mechanical valves one attains rather high levels of sound pressure (to 180 dB). However, they are characterized by certain drawbacks, among which are the presence of moving elements (valves) in the high-temperature zone, their wear in the process of operation, and the necessity of synchronizing the stages of the process.

In the chambers with aerodynamic valves, there are no moving elements and hence none of their related drawbacks [2].

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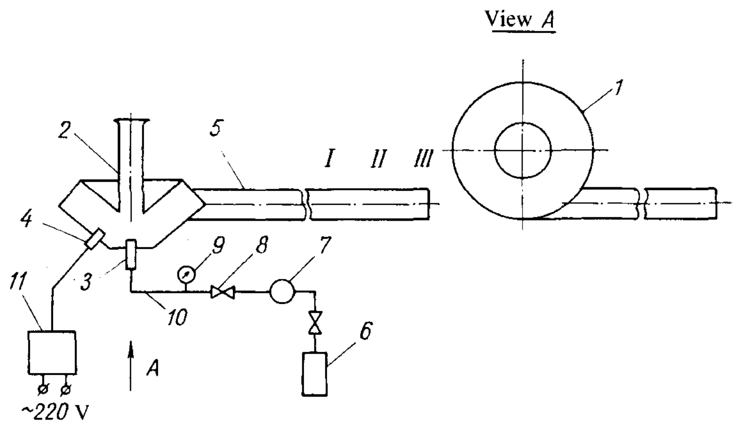


Fig. 1. Diagram of an experimental setup.

In the present work, results of experimental investigations of a cone tangential chamber of pulsating combustion with an aerodynamic valve are discussed. A diagram of the experimental setup is given in Fig. 1. The setup incorporates a PCC that consists of the cone combustion chamber 1, aerodynamic valve 2, burner 3, electric plug 4, and resonance tube 5. The chamber is connected to a system for supplying a fuel gas consisting of the gas source (cylinder with propane-butane) 6, flow-rate meter 7, control cock 8, monitoring manometer 9, and gas duct 10. Voltage to the electric plug was applied from the high-voltage transformer 11. The pulsating-combustion chamber is equipped with metering and recording devices.

The setup operates as follows. At the moment of startup, air is supplied to the combustion chamber 1 from a fan or a compressor; simultaneously the propane-butane gas is injected into the air flow through the burner 3 along the gas duct 10 into the chamber. The amount of the gas and its pressure are monitored by the flow-rate meter 7, the manometer 9, and the control cock 8. The mixture formed is ignited by the electric plug 4, and the pressure in the chamber increases; a major portion of the combustion products is removed from the chamber through the resonance tube 5 and a small amount – through the aerodynamic valve. This is attained by the aerodynamic resistance of the valve being higher in the backward direction than the resistance of the resonance tube. In motion of the main flow through the resonance tube a vacuum is produced in the chamber, and fresh air begins to enter the chamber. Here, it forms a mixture with the fuel; the mixture is ignited by the hot chamber walls or by the fragments of the burnt gases from the previous cycle. After the ignition the air blowing and electric plug are switched off, and the chamber begins to operate independently. The thermal capacity of the chamber is controlled by the flow rate of the fuel. It should be noted that the chamber has a limitation on the flow rate of the fuel; when its supply is excessive the flame can die out.

In this structure, the aerodynamic valve is a device that ensures lower resistance in gas motion in the forward direction (when the gas moves into the chamber) and higher resistance in the backward direction. The venting effect of the valve makes it possible to provide the combustion chamber with air due to the kinetic energy of the combustion products. In this case, blowing devices become unnecessary; supercharging of the chamber is required only at the moment of startup, after which it operates in a self-oscillating regime.

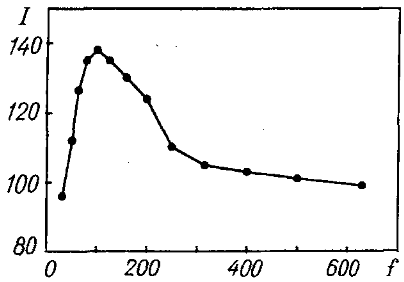
To ensure the self-oscillating regime and certain parameters, the dimensions of PCC elements must be mutually matched [2].

As a result of the experiments conducted, we investigated the composition of the combustion products, the level of sound pressure, and the gas temperature at different points of the resonance tube.

Drying of materials directly by combustion products improves the efficiency of drying units as compared to drying by hot air heated in vapor or gas air heaters. However, the presence of harmful substances in exhaust gases from underfiring and various impurities contaminate dried materials. Consequently, in units for drying of materials (especially foodstuffs), furnace devices must ensure a rather complete combustion of the fuel.

TABLE 1. Composition of Combustion Products

Chemical compound	Units of measurement	Amount
NO	PPM	38
CO	PPM	1538
CO_2	%	8.3
NO_x	PPM	38
O_2	%	8.4



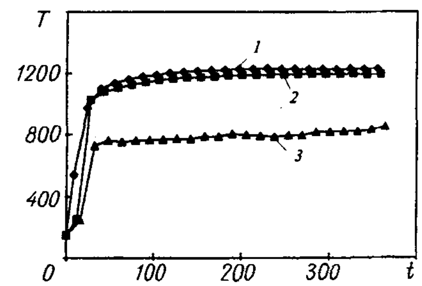


Fig. 2. Intensity of sound pressure vs. frequency. I, dB; f, Hz.

Fig. 3. Temperature in the PCC resonance tube vs. time: 1) at point I; 2) II; 3) III. T, °C; t, sec.

The composition of the combustion products was investigated using a Testo-350 analyzer of stack gases. The analyzer's sensor was positioned at the center of the outlet section of the PCC resonance tube. In the experiments, the excess pressure of the fuel (propane-butane) in front of the burner was maintained in the range of 60–75 kPa. The measurement results are given in Table 1. It should be noted that as the chamber was heated the content of CO significantly decreased. There was no cooling of the chamber in the experimental setup. The presence of SO_2 and NO_2 was not detected.

The action of acoustic vibrations undoubtedly intensifies the process of heat and mass transfer when various materials are dried. However, of significance are acoustic-field parameters: the level of sound pressure, frequency, etc. It is known that the effect of acoustic vibrations begins to show up noticeably at the level of sound pressure above the critical value. In this connection, we investigated the level of sound pressure as a function of the frequency of vibrations of the medium. The measurements were performed using a TOA III three-octave analyzer of the PFT Company (Germany) that permits determination of the voltages of the bands (of sound pressure) of frequency components in the mixture of frequencies in the frequency range of 1.7 Hz to 190 Hz. As the sensor we used a microphone of the Brüel and Kjer Company (Denmark) and an MD-200 dynamic microphone. The microphone was installed on a section of the resonance tube so as to eliminate the possibility of the exhaust gas arriving at its diaphragm, i.e., the diaphragm was arranged in parallel to the axis of the resonance tube. For the frequency investigated, we determined the level of voltage, and then, employing the characteristics of the sensor, calculated the level of sound pressure by the formula $I = 20 \ln (P/P_0)$, where P_0 is the threshold value of the sound pressure, $P_0 = 2 \cdot 10^{-5}$ Pa. The spectral dependence of the level of sound pressure on frequency is given in Fig. 2. From the analysis of the dependence obtained it follows that this PCC has a level of sound pressure of 130–140 dB at frequencies of ~80–150 Hz. The pressure of the fuel in front of the burner did not exceed 80 kPa.

The gas temperature was measured with Chromel–Alumel thermocouples located at points I–III, the distance between which was 400 mm (see Fig. 1). A KSP-4 potentiometer served as a recording device. The temperatures of the gas flow as functions of time are given in Fig. 3. It is seen that the temperature of the combustion products in motion in the resonance tube decreases and, at the outlet from the PCC, is ~800°C with an excess pressure of the fuel gas in front of the burner of 35 kPa. The outlet temperature of the gas increases with flow rate of the fuel. It should be noted that moist dispersed materials and solutions can be injected into a high-temperature pulsating gas flow in the outlet section of the chamber or into the resonance tube via an orifice located nearer to the outlet section. The short duration of the action and high intensity of the heat- and mass-transfer process make it possible to ensure small values of the material temperature.

In conclusion, summarizing the results of the investigations performed, we note that a tangential PCC can be used for efficient drying of dispersed materials and solutions.

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NOTATION

f, frequency of sound, Hz; I, level of sound pressure, dB; T, temperature, °C; t, time, sec; P, sound pressure, Pa.

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