The acoustic model of oscillations of gas combustion in coaxial pipes

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Abstract. Organization of pulse combustion mode is one of the possible solutions to the problem of energy efficiency installations using hydrocarbon fuel. For grate combustion of solid fuels, in particular, solid industrial wastes are considered to be promising coaxial system, allowing the admission of secondary air to the combustion zone. In this paper we proposed an acoustic model of oscillations of gas when burning solid fuel in the system is coaxially arranged pipes with natural air supply. The description of the motion of the gas in the system during one period of oscillation.

1. Introduction

It is known that when pulsating combustion is increasing combustion efficiency and acceleration of heat and mass transfer processes in comparison with a uniform flame. These advantages can be used to solve problems and energy saving and the environment.

The aim of this work was to investigate the acoustic properties of the system, obtaining ratios, determining the conditions for the excitation frequency and amplitude of oscillations of the gas.

2. Calculations and physical description of the fluctuation of gas

In [1] was developed a mathematical model of the vibration excitation gas when burning solid fuels in coaxial pipes (Fig.1).

Fig. 1. The model of a coaxial combustor
Scroll to the study for the installation of four sections. The first part of the combustion chamber to the grid that holds the fuel. The second area is the area of heat dissipation, which is located between the grille and the cross-section of the combustion chamber, which introduced a resonance tube. The third section is an annular channel between the tubes, which served the secondary air. The fourth plot is a resonance tube, which moves the hot gas.

The calculations were performed by power method \[2,3\] for the combustion chamber with an inner diameter of 60 mm, a resonance tube with an inner diameter of 36 mm and a wall thickness of 1 mm, a gas Temperature of 1073 K in the combustion zone and a gas temperature of 673 K at the output of the resonance tube length 1.2 m is taken from \[1\]. The analysis of oscillations of gas was carried out under the condition that the length of the combustion chamber is 0.4 m, the length of the resonant pipe is 1.2 m, \(x^* = 0.24\) m, \(x_{c,r} = x^* + 0.01\) m In this case, the excitation of the gas oscillations with a frequency of 201 Hz and a sound pressure level in the combustion zone 136,7 dB.

For greater clarity, using a single for all sections of the reference system, and as one of the coordinates of the selected longitudinal coordinate, corresponding to the combustion chamber. Replacement of coordinates is performed as follows \(x_3 = l_c - x, x_4 = x - x_{c,r}\).

As a single parameter that defines the amplitude of the pulsation velocity and pressure in the system will take the amplitude of the pressure pulsations in the combustion zone\[1\]:

\[ p_1 = p_{1,m} \sin \left( \frac{\omega x^*}{c_1} + \varphi_1 \right), \]

where \(p^*\) is the amplitude of the pressure fluctuations in the cross-section \(x = x^*\), \(p_{1,m}\) is the amplitude of the pressure fluctuations of gas in the combustion chamber, \(\omega\) - angular (circular) frequency \(c_1=343\) m/s is the speed of sound, \(\varphi_1 = -0.61 \omega R_c/c_1\), \(R_c\) is the radius of the combustion chamber.

Substituting this expression into the equations describing the fluctuations of velocity and pressure in the system \[1\], we can calculate the magnitude of the pulsations of velocity and pressure at any cross-section of each section of the system at any point in time.

It was assumed that at the initial moment of time the pulsations of the gas pressure at all points of the system is zero. At the same time, the amplitude of the pulsations of the gas velocity in each point of the system has a maximum value (Fig. 2, a). In the lower part of the combustion chamber (graph 1) pulse speed primary air is directed from the inlet to the combustion zone. In the annular channel pulsatile velocity secondary air though and has the opposite direction, but also as in the first case directed towards the combustion zone. Therefore, at time \(t = 0\) in the combustion zone receives the maximum amount of air. The amount of the pulsation flow volumes of the primary and secondary air is equal to the pulsation of the volume flow of combustion products included in the resonance tube (Fig. 3, a).

![Fig. 2. Distribution of (a) the velocity fluctuation of the gas in the system; b) pressure pulsations in the system when \(t = T/4\)](image)
Therefore, the pulsation velocity of the gas in each part of the resonance tube is directed away from the entrance to the middle (left part of the graph 3). In section $x=0.64$ m, located somewhat below the middle of the resonance tube, the pulsation rate of the gas is zero. A characteristic feature is that the amplitude of the pulsation velocity inlet gas resonance tube is less than the open exit. For comparison, we note that the distribution of the gas velocity in the pipe, open at the ends, symmetrically relative to the middle.

Despite the equality of the pulsation flow volumes of cold air and hot combustion products, the difference in density leads to an increase in the mass of the gas in the combustion zone (Fig. 3, b). Therefore, over time the pressure of the gas in the combustion zone begins to rise. This reduces the pulsation rate of the primary and secondary air. The increase in the mass of gas in the middle part of the resonance pipe increases the gas pressure in this area and causes a reduction of the pulsation of the gas velocity across the pipe. After a quarter of the oscillation period pulsation velocity of the gas in the entire system becomes zero. As expected, at the entrance of the combustion chamber, the upper end of the annular channel and the output of the resonant tubes are open, the pressure increases slightly (Fig. 2, b). When approaching the combustion zone, the air pressure in the combustion chamber and the annular channel increases and reaches a value equal to the pressure of the hot gas inlet in the resonance tube. However, the greatest compression of the hot gas is in section $x=0.64$ m, where, as previously established, there is no pulsation of the gas velocity.

![Graph](image)

**Fig. 3.** Changes ripple volumetric gas flow (a) and pulsation mass flow rates of gas (b) in the combustion zone for the period of oscillation of gas: 1 - primary air, 2 - secondary air, 3 - combustion products

The gradient of gas pressure at sites 1 and 3 such that the direction of the velocity fluctuation of the air (Fig. 4, graphs 1, 2) becomes the opposite of what it was at $t = 0$ (Fig. 2, graphs 1, 2). This leads to a reduction of the mass of gas in the combustion zone, which is not compensated by the inflow of gas from the resonance tube (Fig. 3, b, the lower part of the graphs 3). The gas pressure in the combustion zone begins to decrease. In the resonance pipe is gas flow, since the pressure in the middle part of the tube exceeds the pressure at its ends (Fig. 2, b). The pressure in this pipe is gradually reduced. At the time when $t = T/2$ the pressure in the entire system becomes equal to its average value, that is, the sound pressure becomes equal to zero. Pulsatile velocity of the gas over the entire system reaches maximum values and aims according to Fig. 4, and. Despite the fact that the pressure gradient vanishes, the gas particles continue to move by inertia. Reducing the mass of the gas in the combustion zone and in the middle part of the resonance pipe leads to a decrease in gas pressure. At each site of the system is the pressure gradient, which inhibits the movement of gas. At the moment when $t = 3T/4$ there is a maximum negative pressure of gas in the system, and pulsation velocity of the gas becomes equal to zero. In the middle part of the resonance pipe - maximum dilution gas, and the pressure in the cross section $x=0.64$ m lower than in the combustion zone (Fig. 4, b, graph 3).
Fig. 4. Distribution of (a) the velocity fluctuation in the gas system when $t = T/2$; b) pressure pulsations in the system when $t = 3T/4$

The gradient of gas pressure in the lower part of the combustion chamber, the annular channel, the lower and upper parts of the resonance pipe is such that further leads to pulsating gas movement in the directions indicated by the arrows in Fig. 2, and. The gas is gradually accelerated. Thus there is an increase in the mass of the gas in the combustion zone and the resonant pipe (Fig. 3, b). This leads to a gradual increase of pressure up to its average value in the system. After the period of oscillation of the distribution of the velocity fluctuation and the gas pressure in the system take the form as in the initial moment of time (Fig. 2, a).

So, as a result of the calculations is given a vivid physical description of the gas oscillations occurring during pulsation combustion of solid fuel is coaxially arranged pipes.

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