Acoustic energy generation by the burning fuel layer

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Abstract. This article studies the process of acoustic energy generation by layer of burning solid fuel in an oscillating air flow. Studied the results obtained for combustion in an open tube. It has been shown that the introduction of the correlation function can be used to determine the acoustic energy generated in the combustion chamber of device capacity-tube type. Received the empirical expression for this correlation function.

1. Introduction
It is known that fluctuations in gas positive effect on the combustion process and the heat-mass transfer in power plants [1-3]. For efficient combustion of solid fuels are widely used devices such Rijke tube. The main problem of theoretical research pulsating combustion in such systems - calculation of acoustic energy generated by the burning fuel layer. Expression defining this energy for burning in an open tube is known. The purpose of this work - to get a similar expression for the combustion of solid fuels in the device capacity-tube type.

2. Relations for open tube
Self-excitation of the gas oscillations in combustion engines due to the generation of acoustic energy in the combustion zone [4, 5], which is

\[ A_c = \frac{(B - 1)S_t U_{1,0}}{Q_0} \left\langle \text{Re}(p') \text{Re}(q') \right\rangle_t \]  (1)

where \( B \) the ratio of the gas temperature behind combustion zone to the temperature of the gas before combustion zone, \( S \) and \( U_{1,0} \) – the cross-sectional area and mean velocity of the flow entering the combustion zone, respectively, \( Q_{1,0} \) and \( q' \) - are average and pulsating heat release rate, respectively, \( p' \) - the acoustic pressure.

Pulsating rate of heat release associated with the velocity fluctuations of gas before combustion zone by relation \( q' = K_u u_1' \) [6, 7]. The transfer function of the flame on the device Rijke tube type (Figure 1a) known [8, 9] and has the form

\[ K_u = \frac{\exp(-i\omega \tau_u)}{\sqrt{1 + (\omega \tau_1)^2}} , \] (2)
where $\omega$ – the angular frequency, $\tau_1$ - the time of inertia, $\tau_u$ - the time lag of heat release rate fluctuations with respect to the air velocity fluctuations.

![Figure 1. The experimental setup.](image)

3. Correlation function for device capacity-tube type

Another device is shown in Figure 1b. In [8], the diameter of the combustion chamber was more than 3 times the tube diameter. Gas oscillations were excited when the fuel layer located near the outlet air supply tube. There is a minimum and maximum distance between the bottom of the combustion chamber and the fuel layer. In the middle of this interval is the maximum amplitude of the oscillations of gas. The reason is that when the fuel layer is almost over output air supply tube, air velocity fluctuations are small because of the large acoustic impedance. Moving up the fuel layer reduces the resistance and increases the amplitude of pulsations of air velocity to the maximum value. Further increase the distance between the bottom of the combustion chamber and the fuel layer leads to that the airflow is fully expanded in the combustion chamber and pulsating air velocity is reduced to a value of $u_\ast = (S / S_c)u_1$, where $S_c$ - the cross sectional area of the combustion chamber.

Amplitude pulsations of air velocity and heat release rate decreases and gas oscillations disappear.

We introduce the correlation function relating the pulsation air to fuel layer with pulsations of air velocity at the outlet air supply tube $u_\ast = \psi u_1$. The expression for the velocity fluctuations of heat has the form $a' = \psi K_u u_1$, and the formula (1) retains its form.

In [8] the function $\psi = 1 - x_\ast / x_m$, $x_\ast$ - a distance from the bottom layer up to the combustion chamber, $x_m$ - a distance corresponding to the oscillation damping. Calculations have shown that the results obtained for small values $x_\ast$ do not agree with the experimental data. We represent the correlation function in the following form

$$\psi = (S / S_0)(a + b\xi_\ast + c\xi_\ast^2 + d\xi_\ast^3),$$

where $\xi_\ast = x_\ast / R_0$, $R_0$ - the radius of the air supply tube.

According to experimental data [8], for combustion of 6 fuel particles, $R_0 = 0.02m$, $S / S_c = 0.1$, oscillations are excited when $0.1 \leq \xi_\ast \leq 0.6$, and the maximum amplitude of the oscillations
corresponds to \( \xi_* = 0.3 \). Analysis of the total volume of the data showed that \( \xi_* = 0.075 \) - limit for the excitation of oscillations, that is \( \psi = 0 \). Other values of the correlation functions were calculated from the relations that determine the conditions of excitation and amplitude of the oscillations [8]: \( \psi = 0.05 \) for \( \xi_* = 0.1 \) and 0.6, \( \psi = 0.72 \) for \( \xi_* = 0.3 \). This data corresponds to the following correlation function,

\[
\psi = S / S_c \left( -6 + 80 \xi_* - 186 \xi_*^2 + 116 \xi_*^3 \right). \tag{3}
\]

which allows to calculate the acoustic energy generated by burning wood particles layer in the device capacity- tube type with any geometrical parameters.

4. Conclusion.
Because correlation function depends on the geometry and location of layer in the combustion chamber, the expression (3) can be used in other cases, the pulsation combustion of solid fuels. If the transfer function of the flame (2) is determined, the acoustic energy generated by the burning fuel layer in devices such as capacity-tube is according to the formula (1), where the right side is multiplied by the correlation function (3).

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