CONDITIONS OF EXCITATION OF SOUND FOR CONDENSED AND GAS FUELS

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Abstract
It is shown that the reverse connection between the acoustic oscillations of the pressure and the burning rate is supported by the vortex motion of gas near the "singing" flame in model combustion chamber. The conditions of exciting of the sound are obtained for the diffusion flames of condensed and gaseous fuels. Also the kinetic flames of propane-air mixtures were studied. The changed parameters were: the velocities of the fuel and burning products, ratio of the diameters of the burner and the tube-resonator. The kind of the fuel determines the profiles of the temperatures and velocities in combustion chamber. It is found that there is the dependence between the sound power and the flame structure. The most minimal heat power that excites the sound is obtained for the flame of the condensed fuel. The influence of the forced convective flow is studied. The explanation of the experimental results is presented.

INTRODUCTION

The evolution of the autooscillating burning process and, as a consequence, exciting of the "singing" flame in the round resonator-tube is caused by two main physical phenomena. The first of them is the instability of the free convective flow near the flame. The second is the feedback between the heat release rate in the flame and the heat transfer.

The instability of the convective flow becomes apparent as low frequency oscillations of the flame. The flame can oscillate as a body. Sometimes only any parts of the flame oscillate. It can be explained by the influence of the variable heat and mass-transfer on the rate of the diffusion combustion. These two modes of the oscillations are possible at the minimal heat power of the flame. The amplitude of the oscillations becomes greater if the frequency of the flame oscillations is equal to the resonance frequency of the combustion chamber.

At present there is not a clear idea about the controlling mechanism of feedback between oscillations of the heat evolution rate and the pressure oscillations in combustion chamber. The convective heat and mass-transfer in the vortex structures near the flame is one of the possible controlling mechanisms if the modeling combustion chamber is the vertical round tube. It is necessary to find out the conditions of exciting and attenuation in specific hydrodynamic situations in order to ascertain the characteristic signs of this mechanism. Besides, it is necessary to determine the connection between the characteristic times of the vortex structure formation, changes of the temperature field, heat and mass-transfer and the period of the pressure oscillations.

Experimental method

The conditions of excitation of acoustic oscillations by a diffuse flame of gasoline in model combustion chamber were studied. The influence of the pressure oscillations on the rate of the fuel feed was excluded by using the flame of condensed fuel. The surface of the porous wick provides the specific boundary conditions for the formation of the vortex structures. Also the change of the combustion rate under influence of the acoustic oscillations was studied.

The experimental setup comprised a base on which an immobile cylindrical tube with an internal diameter of 0.085 m and a length of 1.8 m was vertically mounted. A mobile cylindrical sleeve with an external diameter of 0.080 m was suspended on a spring inside the tube. The length of a mobile cylindrical sleeve was taken equal to the inner tube diameter (0.085 m), since previous experimental results reported in [1-3] indicate that the inner diameter of the tube determines the maximum size of the vortex cell. The mass of the sleeve was 24.5 g. The coefficient of stiffness of the spring was $k \leq 0.14$ N/m. This design allowed for measuring the energy of gas vortex motion within a limited region of a tube as described previously [3]. At one-quarter of the immobile tube from its lower edge was placed a heat source representing either a diffuse flame of gasoline burner or an electrical heater coil. The height of the porous wick of the burner was varied in order to change the heat power of gasoline burner. The heat power of the burner or electrical heater coil could be varied from 10 to 120 W. The voltage applied to electrical heater coil was varied from 20 to 40 V, whereby the current changed from 0.5 to 3 A. The temperature of the combustion products was measured to within 10^{o}C using a thermocouple mounted at the center of the resonator-tube, at a distance of 0.1 m from its upper edge. The velocity of combustion products at the upper edge of the resonator-tube was measured by a rotameter. The heat power of the burner was calculated using the reference data about the specific enthalpy of the fuel and the results of the measurements of mass rate of combustion. Then the obtained values of the heat power were compared with these one for electrical heater coil.

The intrinsic frequency of the gas column in the resonator-tube was 90 Hz. As the heat source power increased, an increment in the gas velocity oscillation amplitude exceeded the constant component, which resulted in the flame breaking and quenching. The results of experiments show that coincidence of the specific times of diffusion, vortex structure formation and gas column oscillation period determines the possibility of the exciting of acoustic oscillations.

The results of determining the energy W of acoustic oscillations as a function of the heat source power P are presented in the figure 1, where curves 1-3 correspond to the cases of singing diffuse gasoline flame, propane flame and Rijke tube, respectively. The autooscillations are excited at a heat source power of 45 and 55 W. In all cases, the maximum amplitude of autooscillations is achieved at a heat source power ≈ 90 W. As can be seen in the figure, a decrease in the power leads to hysteresis in *W(P)*. This behavior is probably related to the fact that the vortex flow is more stable than translational motion.

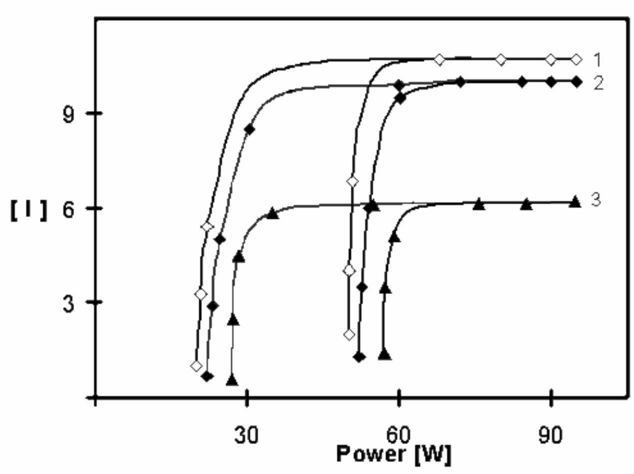

Figure 1 – Hysteresis dependence W(P)

The evolution of acoustic oscillations in the combustion chamber cases the decrease of the height of the flame and the burning rate of the liquid fuel, while maximal temperature and the completeness of combustion increase. The flame is getting turbulent at the great amplitude of the oscillations, though the ambient free convective flow remains laminar. Using the method of the program processing for digital photograph of the luminescence of the flame, it is possible to evaluate the change of the temperature field in the flame during the period of the one oscillation. The photographs of the distribution of the luminescence in the stable and oscillating flame are presented in the figure 2. Every color line corresponds to the definite value of the energetic luminescence of the flame. The evaluation method of the temperature field is based on the Stephan-Boltzman law and the decision the integral equation describing the distribution of the energetic luminescence in the flame. As it can be see in figure 2 the decrease of the height of the flame and increase of the temperature gradient occurs near the wick.

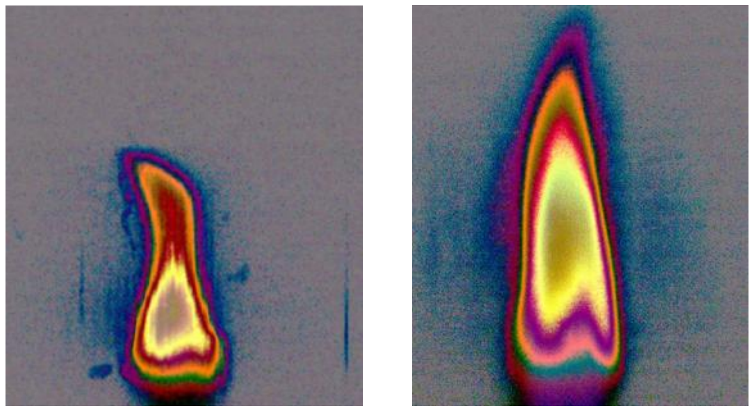

Figure 2 – Photographs of luminescence of stable and oscillating gasoline flame

The graphics of the dependence of the combustion rate and the energy of acoustic oscillations are presented in figure 3, where curves 1-2 correspond to the cases of singing gasoline flame and stationary gasoline flame, respectively. It can be see in figure 3 that the combustion rate is getting less when the flame is oscillating. It can be explained by the increase of the heat and mass transfer, caused by gas motion in the vortex structure. Besides, the stay time of the combustible particle of the liquid fuel in the zone of burning increases. This is the reason of the increase of the combustion completeness at the acoustic oscillation regime.

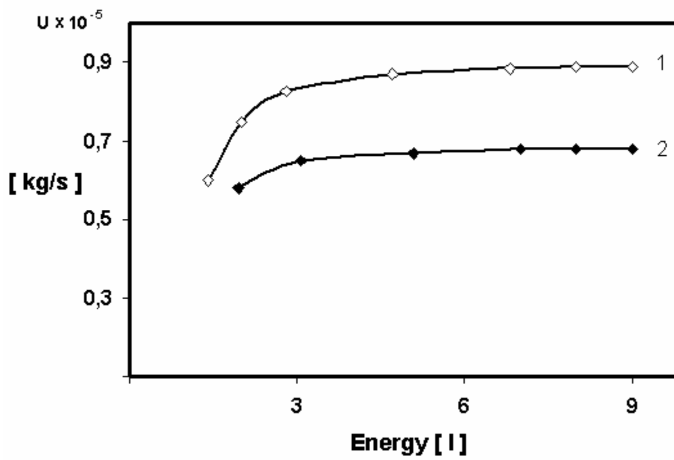

Figure 3 – Dependence of combustion rate on energy of acoustic oscillations

SUMMARY

The mechanism of feedback between autooscillations of the flame and the heat evolution rate can differ in dependence on the way of supply of fuel to a combustion chamber. The determining parameters for the wick burner are the characteristic times of the evaporation and combustion of the fuel particle. The characteristic time of swirling of gas in the vortex cell is determined by acoustic properties of the combustion chamber. The increase of the resonance frequency of the combustion chamber can damp the acoustic oscillations of the flame on the wick burner.

The influence of the acoustic oscillations on the combustion rate is conditioned by two reasons. The first of them is the feature of hydrodynamics of the vortex motion in the resonator-tube at small Reynolds numbers. In the previous work [3] it was be shown that the main energy of the vortex motion is concentrated in the region of the singing flame (heat source). The second is connected with the Richardson annular effect determining the position of maximum of the rotational vortex motion near the wall. Kinetic energy distributions for the rotational motion in a singing flame and the Rijke tube are similar. This coincidence indicates that the feedback mechanisms accounting for realization of the Rayleigh principle for the excitation of thermal autooscillations are related to the vortex structure formation in a gas flow.

The rotation vortex motion changes its direction twice during one period of the oscillation. Independently on the direction of the rotational motion the vortex cell provides the transfer of oxygen from air to the flame in greatest degree. The decrease of the height of the oscillating flame can be explained by the decrease of the average translational velocity of oscillating flow in the resonator-tube. This influence is proportional to the amplitude and frequency of the acoustic oscillations.

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