GASDYNAMIC STIMULATION OF COMBUSTION OF LEAN FUEL MIXTURES. 2. EVALUATION OF THERMODYNAMIC PARAMETERS AND THE MAGNITUDE OF HEAT LOSSES

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Various gasdynamic regimes of combustion of a lean fuel mixture of propane with air, including combustion of the mixture at rest, combustion with annular twisting of the gas, and combustion stimulated by jets of a burning gas injected into the combustion chamber (PJC) were analyzed from the viewpoint of the magnitude of heat losses. The advantage of PJC over other combustion regimes is shown. We suggest a simple method to evaluate the pressure increase by calculating the magnitude of the energy release with allowance for heat losses to the combustion-chamber walls.

The preceding part of the work was devoted to experimental investigation of various gasdynamic regimes of combustion of lean fuel mixtures [1]. We showed that the gasdynamic structure of the flow in the combustion chamber exerted a most direct effect on the process of energy release, thereby determining the time of combustion, the magnitude of heat losses and, consequently, the pressure increase, and the final temperature of the combustion products.

It should be noted that the thermodynamic parameters for fuel combustion in a closed constant volume with a complex surface of the flame front can be calculated using various relatively accessible algorithms [2-4]. And moreover, correspondence between the calculated and measured values of the pressure in the combustion chamber can be attained only when the volume fraction of the burnt gas can be accurately taken into account in the calculations. In this connection we made an attempt to analyze the thermal efficiency of the previously experimentally investigated combustion regimes based on a simplified technique of calculation of heat losses and to evaluate the pressure increase in the combustion chamber. However, we did not consider the process in dynamics, but instead at each instant of time we analyzed the equilibrium thermodynamic parameters behind the combustion-wavefront for a given volume fraction of the burned gas and a known area of contact of the combustion products with the wall.

It is evident that the magnitude of the maximum increase in pressure in the chamber depends first of all on the duration of the combustion process. The faster the combustion, the smaller the heat losses and, consequently, the higher the increase in pressure. Moreover, the thermodynamic parameters of the combustion products and the magnitude of the heat losses may also depend on the structure of the gasdynamic flow in the combustion chamber, which determines the duration and area of the contact of the combustion products with the wall. As an example, Fig. 1 presents oscillograms of the pressure change in the combustion chamber for different techniques of ignition of the fuel mixture. The initial pressure in the chamber was 0.18 MPa, and the combustion was initiated in a premixed gas mixture of propane with air, with the excess-fuel coefficient being 0.7. The time of combustion was defined as the time interval between the instants of ignition and attainment of maximum pressure in the combustion chamber. As follows from the given oscillograms, the minimum time

Fig. 1. Typical oscillograms of the pressure in the combustion chamber for different regimes: 1) initiation of combustion by burning-gas jets (PJC); 2) spark initiation in annular twisting of the gas; 3) laminar combustion initiated by spark ignition. $P$, MPa; $t$, msec.

The increase in pressure in the combustion chamber in an adiabatic approximation was calculated based on the equations of mass and energy balance between the initial and final products with allowance for the equation of state and the thermal effect of the reaction:

$$\sum [m_c (\Delta E_c)_{T_f}] = \sum [m_c (E^T - E^F)] ;$$

$$\sum m_c = \sum m_i ;$$

$$P_c = P_1 (T_f/T_i) (\sum m_c/\sum m_i) .$$

Here $m_c$ is the number of moles of burned gases; $m_i$, $m_c$ and $E^T$, $E^F$ are the total number of moles and the amounts of the internal energy of the corresponding components before and after combustion. The technique of calculation of the temperature and pressure is described in detail in [5].

The magnitude of the heat losses was calculated assuming constancy of the difference between the temperatures of the flame front and the wall, with allowance for the fraction of the burned gas and the known for complete combustion and, correspondingly, the maximum increase in pressure were recorded in the PJC regime. Here, the higher thermodynamic parameters are due to lower heat losses because of the accelerated course of the process itself, i.e., the shorter contact of the hot combustion products with the cold walls, and also to the smaller surface of their contact, especially in the initial stages of development of the process. The latter is associated with the presence of a gas heat-insulating interlayer between the hot combustion products and the wall, which favors a decrease in the removal of heat from the zone of combustion.

To analyze the efficiency of various regimes of combustion, we evaluated the increase in pressure and the heat losses in regimes of laminar combustion, gas twisting, and PJC initiation. Calculations were carried out for regimes of combustion of a propane–air mixture with a coefficient of excess fuel of 0.7 and an initial pressure of 0.2 MPa. The scheme of calculation presupposed the following stages: adiabatic approximation in evaluating the heating and the rise in pressure due to the chemical energy evolved in combustion, evaluation of heat losses, reduction of the energy release by the magnitude of the heat losses, and refinement of the thermodynamic parameters in the combustion chamber.

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The calculation results for the pressure in the combustion chamber in an adiabatic approximation for the various regimes and their comparison with experimental data are presented in Fig. 2. At each instant of time the calculation was performed with account for the fraction of the mixture burned, which was determined from a frame-by-frame display of the process. It is evident that the adiabatic approximation gives a maximum pressure overestimated by 23–60% depending on the regime of combustion. Thus, corrections for the nonadiabaticity of the process and allowance for heat losses are necessary in carrying out an appraising calculation of the thermodynamic parameters in the combustion chamber.

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