Temperature distribution along a pulse detonation combustor in a wide range of ratios between the oxygen-enriched heptane-air mixture components

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1 Introduction

At the present time, the detonation process used for obtaining a jet thrust is being investigated extensively for the purpose of developing of efficient engines for flying vehicles. A detonation engine represents a power plant in which a thrust is generated as a result of controlled detonation of a combustible mixture. Numerous theoretical and experimental research works [1–4] are indicative of the importance and potentiality of this area in the propulsion engineering. In its simplest version, pulse detonation engine is a semi closed tube equipped with a system for supplying and mixing reacting components, igniting the mixture formed, and initiating detonation waves. In the engines operating in a frequency regime, the identical sequence of processes is repeated cyclically such as the supply of reacting substances, formation of a combustible mixture filling the combustor with it, detonation explosion of the is combustible mixture accompanied by a sharp increases in the temperature and pressure, and the outflow of the combustion products outwards yielding the jet momentum. In a pulse-type detonation engine, combustion is initiated with a definite assigned frequency, with the result that the ignition and combustion processes differ somewhat from cycle to cycle because of the change in the conditions of mixing of the fuel with the oxidizer and the effect of the heating of the combustible mixture by the combustion products of the previous cycle, and the variations of the fuel equivalence ratio.

The present work is devoted to the study of the influence of the fuel equivalence ratio of a jet-type pulse detonation combustor (PDC) (a model of a detonation engine) on its thermal state and the temperature distribution along combustor.

2 Experimental

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The investigations were carried out in a pulse detonation chamber with the use of a heptane-air mixture enriched with oxygen. This chamber consists of a semi closed sectional tube of diameter 20 mm and length 664 mm (Fig. 1). The experimental setup is equipped with systems for supplying a fuel, igniting it, and controlling the combustion process. This setup is described in detail in [5, 6].

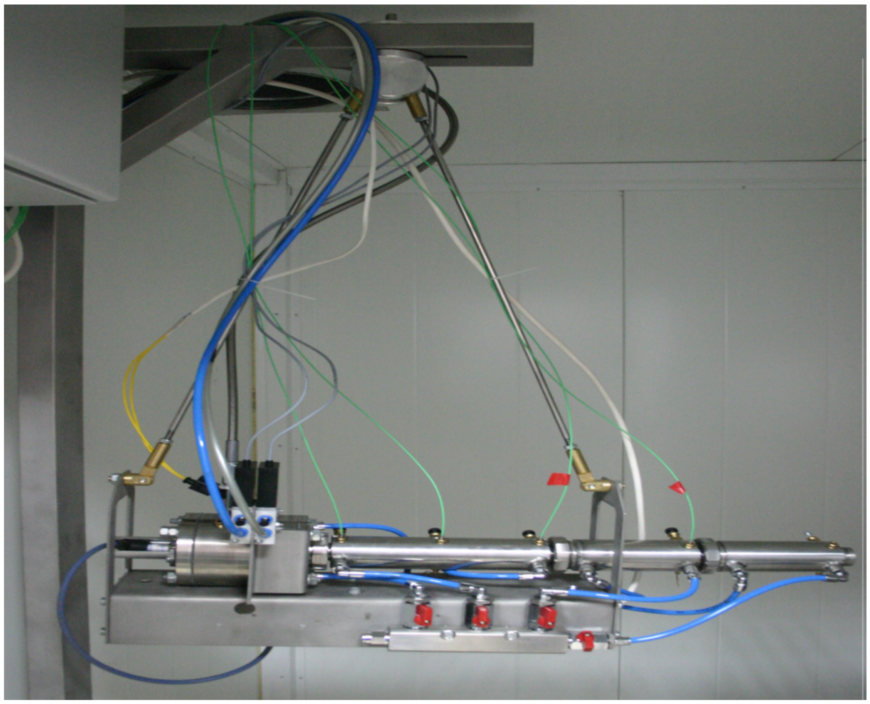

Fig.1. Jet-type liquid-fuel pulse combustor

The pressure profile and the time of the arrival of a shock wave to a pressure transducer were measured in four sections of the detonation tube, which made it possible to calculate the velocity of propagation of the flame front in the sections of the tube located at different distances from the ignitor. The pressures recorded by four pressure transducers, positioned along the tube at distances 140, 240, 340, and 640 mm from the ignitor for a series of five successive cycles of operation of the PDC, are presented in Fig. 2. The fuel-air mixture formed in the prechamber was ignited by an automobile spark plug with a low ignition energy. The plug was positioned at the center of the end wall of the prechamber. The fuel equivalent ratio was varied from 0.95 to 2.57 at a pressure of 1-10 bars in the pipes for air and oxygen.

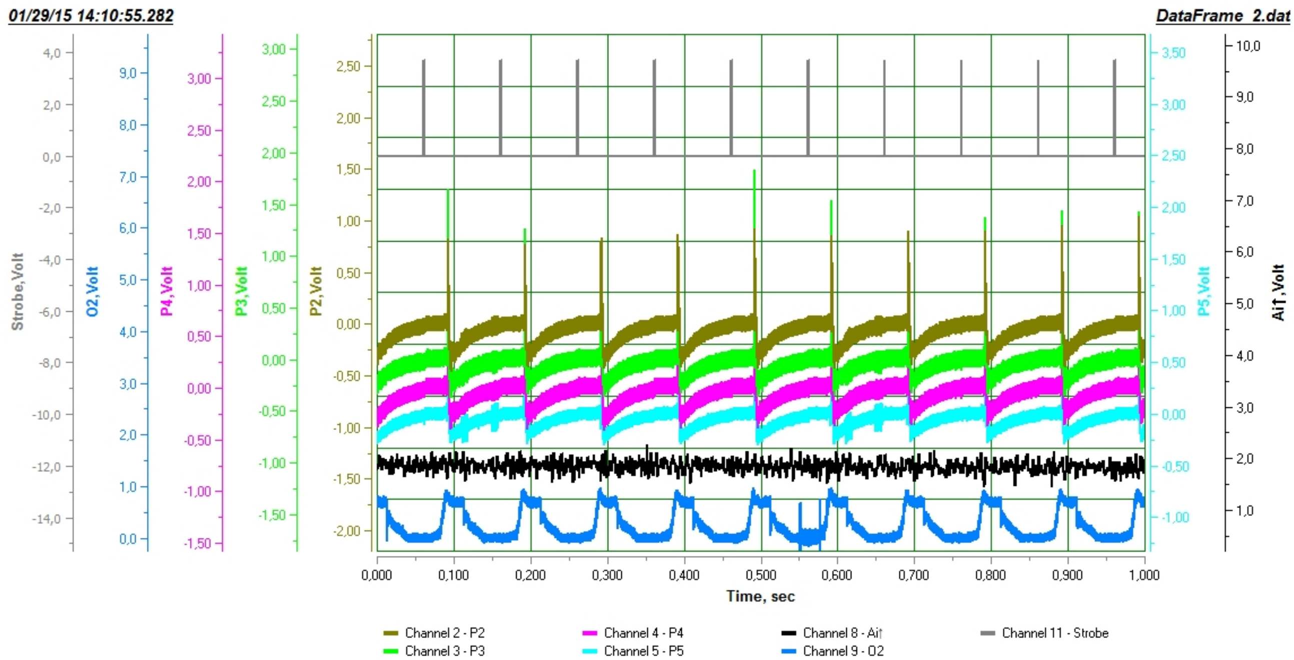

Fig. 2. Registograms of the pressure measured by different pressure transducers (khaki, green, crimson, and blue lines), the flow rates of oxygen (blue line) and air (black line) measured by flowmeters from bottom to top, and the strobe (grey line).
Conversion factors: 18.7 bars / volt for pressure sensors;
200 l/min for air and oxygen flowmeters

3 Results and Analysis

The ignition of the fuel at the closed end of the prechamber formed the combustion front that rushed to the outlet of the detonation tube. In moving through the conical passage that connects the prechamber with the detonation tube the flame front was, enhanced and transformed into shock waves that intensified in the process of their propagation in the fuel mixture filling the tube and developed into detonation waves (Fig. 3). It is seen from Fig. 3 that, after the exit from the prechamber the front forms a shock wave propagating with a velocity higher than 1000 m/s, which subsequently initiates a detonation wave. The lather in the third measurement base accelerates up to a velocity exceeding 2000 m/s typical of an over-compressed detonation for the given fuel mixture with a fuel equivalence ratio
$\phi = 0.77$.

In the regime of heating of the PDC, i.e, before the achievement of a stationary thermal regime, the thermal state of the fuel mixture and the intensity of the combustion wave in the tube under go a change. In this regime, the temperature of the tube walls increases sharply, which leads to an increase in the thermal activation of the mixture and, consequently, to the successive transformation of the fuel drops from the liquid state into the gaseous one. This effect makes the ignition of the fuel and the initiation of shock and detonation waves much easier; this was demonstrated in the work [5]. However, the time of the attainment of a stationary thermal regime in the detonation tube and the maximum temperature of its walls depend substantially on the fuel mixture composition, i.e, on the ratio between its reacting components. Figure 4 shows the temperature distributions along the PDC depending on the fuel equivalence ratio in six sections at different distances from the ignitor. It is seen that the temperature profile in the prechamber not only substantially lags behind the temperature dynamics in the detonation tube but also differs from it in character at one and the same fuel equivalence ratios ($\phi = 0.95 - 2.57$). The temperature difference is $22 - 36$ ℃. In the case where the fuel equivalence ratio in the prechamber increases to $\phi = 1.75$, the temperature increases insignificantly (by no more than 15 ℃). Further enrichment of the mixture has no influence on the temperature in the prechamber (the temperature T_1 measured at a distance of 20 mm from the spark plug).

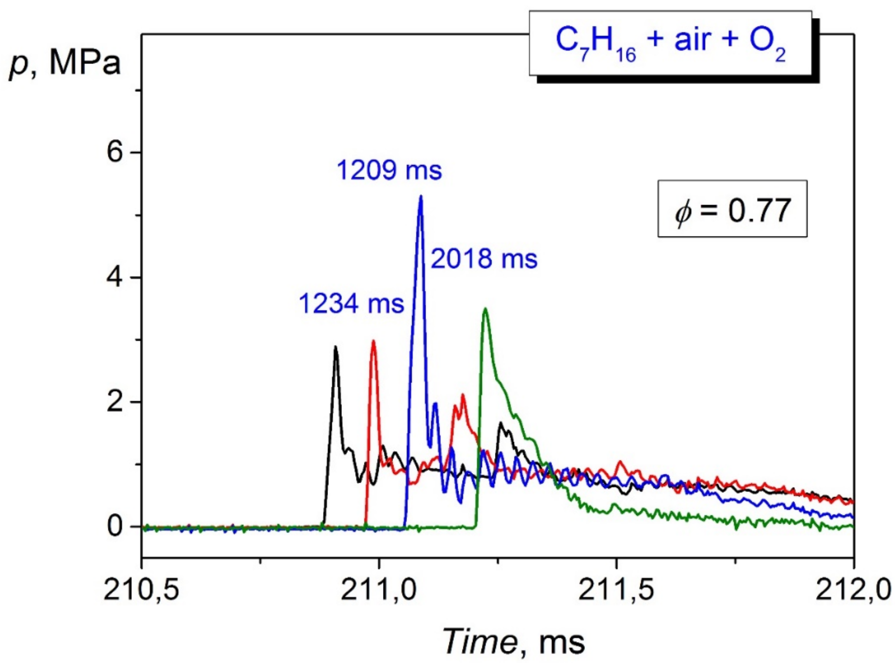

Fig. 3 Dynamics of the pressure along the detonation tube filled with a weak heptane - air mixture enriched with oxygen.

The temperature distribution depending on ϕ, measured at five control points along the detonation tube, is extremum in character, and it has a maximum for a reach mixture with $\phi = 1.75$. On the entire range of ϕ values, then lightest temperature (100 ℃ and higher) was detected in the of the tube adjacent to the prechamber (the temperature curve T_3 in Fig. 4). This effect allows the conclusion that the combustion front at the exit from the prechamber undergoes acceleration, which leads to the formation of powerful shock waves causing detonation over the further path of the combustion front in the tube. It should be noted that the temperature scatter along the detonation tube is not large and comprises not more than 12 ℃. Evidently, the decrease in the temperature of the tube walls after the combustion wave passes the control point (T_3), where the temperature reaches a maximum, is due to the formation of a strong detonation wave propagating with high velocities and to the subsequent evacuation of the tube for the start of the next cycle. This does not provide, favorable conditions for heat transfer to the walls of the tube because heat transfer is an inertial phenomenon effect.

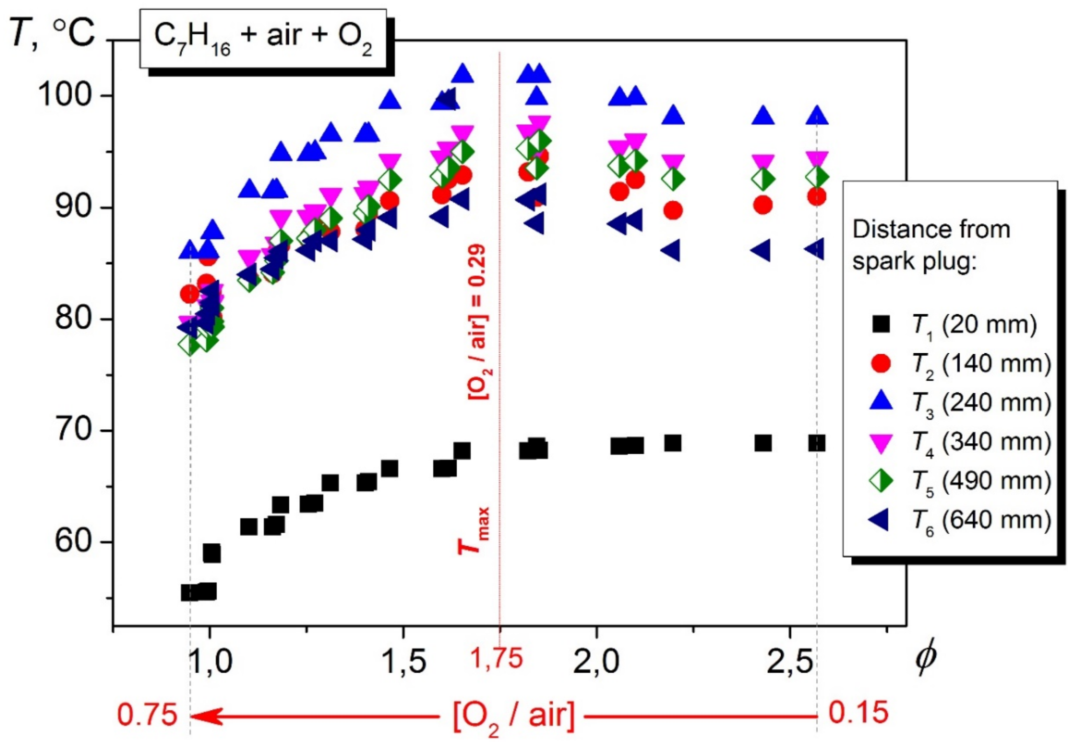

Fig. 4. Dependence of temperature distribution along the detonation tube on the fuel equivalence ratio in the fuel mixture

4 Conclusions

The temperature distribution along the PDC is extremum in character in the range of change in the fuel equivalence ratio studied. The frequency regime of generation of shock and detonation waves deteriorates the heat exchange between the fuel mixture and the environment through the PDC walls. As a result, in the tail part of the detonation tube, the wall temperature somewhat decrease (approximately by $\mathbf{10-12}$ ℃) relative to the peak temperature attained at a distance of 10-14 detonation-tube diameters from the ignitor, e.g, the temperature T_3, was measured at the control point located at a distance of 240 mm from the spark plug (Fig. 4).

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