Influence of the Temperature of a Heterogeneous Mixture on the DDT in a Small-Size Pulsed Detonation Combustor

Alhussan Kh.[1], Assad M.S.[2], Penyazkov O.G. [2]

[1]National Center for Aeronautical Technology, KACST , Saudi Arabia
[2]A.V. Luikov Heat and Mass Transfer Institute of National Academy of Sciences of Belarus, Minsk, Republic of Belarus

1 Introduction

During the past few years, many investigations and publications have appeared that are concerned with the problem of implementing controlled detonation in the aircraft power plants [1–7]. The interest in the detonative combustion of fuel is attributable to the fact that thermodynamically detonation is more efficient than slow combustion (deflagration). The principle of operation of such power plants is based on the excitation of a detonation wave propagating with a supersonic velocity in a combustible mixture and causing high temperatures and pressures, thus generating a large thrust pulse.

The available published works mainly examine detonative combustion of combustible gases (hydrogen, methane, etc.). Unlike the gas detonation that is generated in a premixed mixture, the detonation of liquid fuels propagates in a two-phase medium composed of a gaseous oxidant (air, oxygen) and fuel drops. Therefore the operation of pulsed detonation devices with the use of liquid hydrocarbon fuels has a number of difficulties the main of which are:

- fuel delivery to the oxidant (air/oxygen) flow;
- mixing a fuel with an oxidant over a short length of the tube;
- ignition of a mixture and provision of its stable combustion.

These difficulties compel us to seek the ways of realizing a heterogeneous detonation in pulsed detonation engines (PDE).

The objective of the present work is to study the combustion wave propagation in a small-size pulsed combustor with regard to the influence of thermal activation of a heterogeneous mixture on the deflagration-to-detonation transition.

2 Experimental procedure

To solve the above-said problems a series of experiments were performed with a combustor that is a 20-mm dia partitioned tube equipped with a prechamber shaped as a hemispherical cavity with a conical duct for transition to the tube (Figure 1). The total length

Correspondence to: assad@hmti.ac.by

of the setup was 664 mm. A mixture was ignited forcibly by a spark plug mounted in the closed endwall of the combustor along its longitudinal axis. The fuel was heptane, with air and oxygen serving as an oxidant which was fed through a special nozzle with quick-operating valves. The air and oxygen flowrates changed within the ranges 300…600 l/min and 100…300 l/min, respectively, that were controlled by digital flowmeters.A fuel was injected by an injector located in the zone of intersection of the hemispherical and conical parts of the prechamber.

The fuel injector was calibrated in wide temperature and pressure ranges. Its flowrate at temperatures typical of the LFPDC working process in the present study is 3.1 g/s. The wave velocity in the tube was estimated by the known base method with the use of pressure sensors and ion probes installed in six sections along the tube. Their signals made it possible to determine the mean velocity of wave propagation on five bases with the lengths L_1 = 120 mm, L_2 = 100 mm, L_3 = 100 mm, L_4 = 150 mm, L_5 = 150 mm. The temperature variation along the tube was recorded by six thermocouples (Chromel – Alumel) with the temperature range –40…+1100. The sensitive ends of the thermocouples are fixed in the tube body in six sections at a depth of 1 mm from its inner surface. The setup is completely automated and operates in a cyclic regime with a frequency from 1 to 80 Hz. The setup measuring system allowed us to record the current state of pressure and temperature variations and also the time of wave propagation through the measuring bases. Figure 2 shows as an example the record of the operating process characteristics of the developed liquid-fuel pulsed detonation combustor (LFPDC) for a series comprising ten cycles with combustion of a heptane + oxygen + air mixture at a frequency of 10 Hz.

Figure 1. General view of the LFPDC

3 Results and analysis

Organization of the operating process in the developed LFPDC ensures a high frequency of the pulses, reliable ignition of a mixture, and the combustion wave propagation through the tube. For detonation waves to be generated, it is necessary to excite the mixture by increasing its internal energy. The heating of the LFPDC and simultaneously of the mixture promotes the transition of the liquid fuel into the aggregate state of the oxidant. It is a key factor responsible for the initiation of detonation in a small-size tube of length less than 1 m. In such a scheme a mixture is formed (like the diesel process) as a result of partial evaporation of fuel drops, molecular mixing of the fuel vapors with the oxidant, and of the aerodynamic breaking of drops in the gas flow.

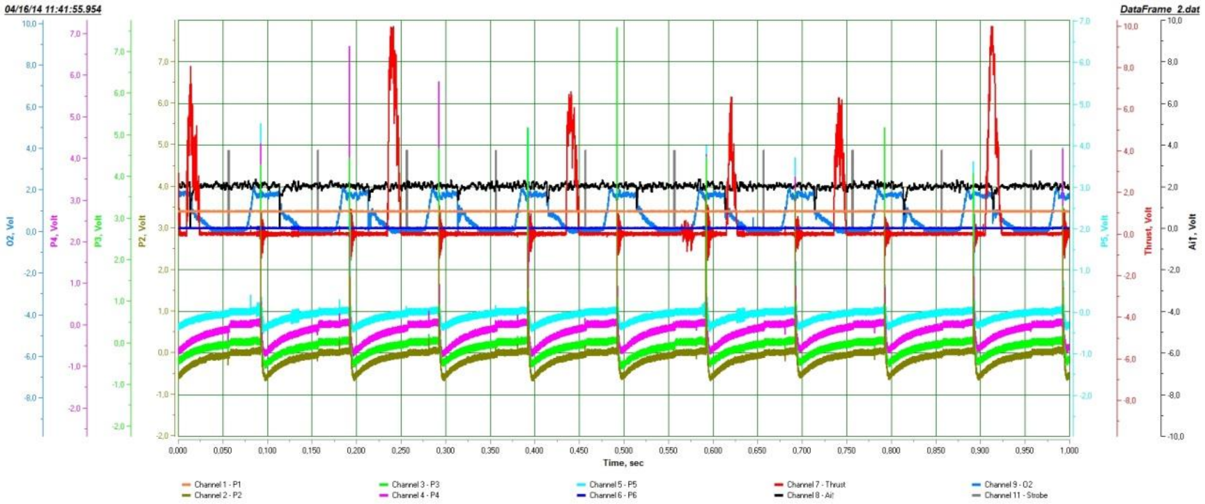

Figure 2. Record of the LFPDC parameters at a frequency of 10 Hz

Analysis of a large number of working cycles in combustion of near-stoichiometric heptane/air/oxygen mixtures (ϕ = 0.95…1.05) has revealed that the wave velocity varies within the range 500–2500 m/s. The detonation was recorded at distances 140–640 mm from the spark plug that is at a distance equal to 7–32 tube diameters. Such a marked spread in the wave velocities and predetonation distances is explained by the degree of thermal activation of the mixture prior to its ignition. Figure 3 presents the dependence of the wave velocity on the prechamber temperature for heptane/air/oxygen mixture over the second, third, and fourth gauge lengths with equivalence ratio ϕ = 1.04. The prechamber temperature varied from 34 to 61°C. It is seen that with increase in the temperature the combustion on the second gauge length is accelerated practically uniformly, but without detonation, with rare exception. Over the third and fourth gauge lengths the temperature influence on the wave velocity is of intermittent character. On the third gauge length with heating one observes a monotonous acceleration of the flame front with a possible transition to detonation at 45–55°C. With a further increase in the temperature, the combustion wave is accelerated practically up to the detonation velocity. The fourth gauge length is characterized by a monotonous acceleration of the flame front at the start of the temperature interval and at 40–45°C the combustion rapidly goes over into detonation. Above 45°C the detonation over this gauge length has a stable character.

Thus we may conclude that the thermal activation of a mixture exerts a substantial influence on the behavior of the LFPDC operation. It not only promotes a deflagration-to-detonation transition but is also decisive for the predetonation distance.

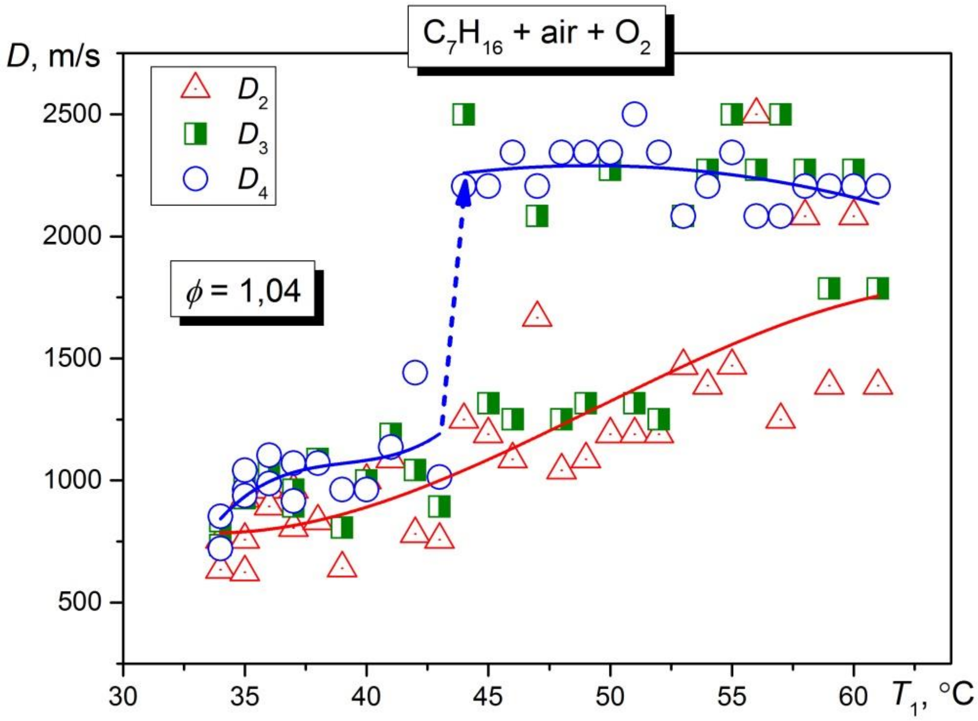

Figure 3. Wave velocity in the LFPDC as a function of the prechamber temperature:
D_2 velocity over the second gauge length;
D_3 velocity over the third gauge length;
D_4 velocity over the fourth gauge length.

References

[1] Higgins A.J., Pinard P., Yoshinaka A.C., Lee J.H.S. High-Speed Deflagration and Detonation. Edited by G.D., S.M. Frolov, D. Netzer, A.A. Borisov. Moscow: Torus Press, 2001, p. 45.

[2] Brophy C.M., Sinibaldi J.O., Wang F. et al. AIAA, 2004, Paper No. 2004-0834.

[3] Shchelkin K.I., Sokolik A.S. Zh. Fiz. Khim., 1937, Vol. 10, p. 484.

[4] Rocourt X., Gillard P, Socket I., Piton D., Prigent A. Shockwaves, 2007, Vol. 16, No. 3, p. 233.

[5] Roy G.D., Frolov S.M., Borisov A.A., Netzer D.W. Pulse detonation propulsion: challenges, current status, and future perspective. Progress in Energy and Combustion Sciences, 2004, Vol. 30, Issue 6, pp. 545-672.

[6] Assad M.C., Alhussan K., Penyazkov O.G., Sevruk K.L. Khim. Fiz., 2014, Vol. 33, No. 3, p. 62.

[7] Galligan C. E., Duboisy C., Stowe R., Kaliaguine S., Niaki H. Heterogeneous catalytic decomposition of JP-10: for use in a pulsed engine. Khim. Fiz., 2005, Vol. 24, No. 7, p. 91.