

DDT in Heptane/Oxygen Mixtures at Low Pressures

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1 Introduction

During the cyclic detonation process, the time of one device cycle will be mainly determined by the deflagration to detonation transition (DDT) time, besides the injecting and mixing times of mixture components, and the removing time of combustion products out of the main chamber.

Moreover, such a parameter as the DDT distance of a working mixture will set minimum geometric dimensions of the combustion chamber and, therefore, engine weight and size characteristics. Also, the detonation cell size will define minimum geometric dimension (inner dimension of detonations channel).

From the viewpoint of safety, convenience of storage and transportation, for pulse detonation devices more preferably to use liquid hydrocarbon fuels, rather than gaseous ones. Consequently, *n*-heptane detonation properties may represent the fundamental interest.

The objectives of this work were to determine characteristic DDT time and distance, detonation cell size values in *n*-heptane and oxygen mixtures at low initial pressures. This data allows to predict the detonation behavior when you need to operate at pressures smaller than normal, for example, when injection of mixture components and emissions of combustion products is carried out in vacuum.

This paper reports preliminary results of detonation investigations.

2 Experimental setup and details

An experimental setup based on heated detonation tube (2.3 meter long, 22 mm inner diameter) was used in our experiments (figure 1).

Investigations were made in stoichiometric, lean, and rich (equivalence ratio $\phi = 1, 0.5$ and 2 , respectively) mixtures of *n*-heptane and oxygen over the pressure range 10 – 60 kPa. Such components as liquid *n*-heptane (reference, GOST 25828-38) and gaseous oxygen (GOST 5583-78) were used to prepare mixtures.

Under normal conditions (temperature is 20⁰C), the pressure of the saturated *n*-heptane vapors is 35.43 mm Hg. Thus, a maximum initial pressure of the C₇H₁₆+11O₂ mixture will be 425 mm Hg in normal conditions (when heptane vapors still will not condense at the tube walls). In order to work over a wider ranges of initial pressures and knowingly to evaporate the whole liquid heptane mass, experiments were carried out at initial temperature 104-105⁰C. A boiling point of liquid heptane is

98.428⁰C. So, completely evaporated heptane/oxygen mixture can be prepared when heating is more than 100⁰C.

A mixture was prepared beforehand in a separate 19.95 l evaporation (mixing) chamber equipped with a batcher for liquid *n*-heptane supply and connected with the gaseous oxygen line. A detonation tube, evaporation chamber, and connecting and supply gas lines were equipped with heating system and were heat-insulated. Heating was made with the use of a.c. heater and transformers. Thermocouples integrated into a temperature controlling system were used to control temperatures of the tube, the chamber and the gas lines.

Prior to series of experiments with certain equivalence ratio, the evaporation chamber was vacuumized by a vacuum pump to a residual pressure no more than 10⁻² Pa. Then Liquid *n*-heptane was supplied to evaporation chamber via the batcher and gaseous oxygen – from the gas line. Further, the evaporation chamber and the detonation tube were heated up to ~ 105⁰C. To organize more intense evaporation and mixing of mixture components the evaporation chamber was provided with a metal ball that periodically rolled in the chamber in the process of mixture preparation. The mixture preparation was in the range of 4-5 hours.

The process of combustion was initiated by electric spark ignition (standard automobile spark plug was located in the end tube flange, ignition energy was ~0.8 mJ) using a high-volt block.

To control the arrival time of the reaction front and to measure the process velocity, the tube was equipped with 22 ion current sensors arranged as a single line at a distance of 65 mm from each other. They allowed to record the conduction current in reaction front with a spatial resolution of 0.5 mm. Output signals of the sensors were recorded by oscilloscopes and then processed on a computer. To avoid confusion in processing of oscilloscope records, sensors were divided into 2 measuring lines, each incorporating 11 sensors.

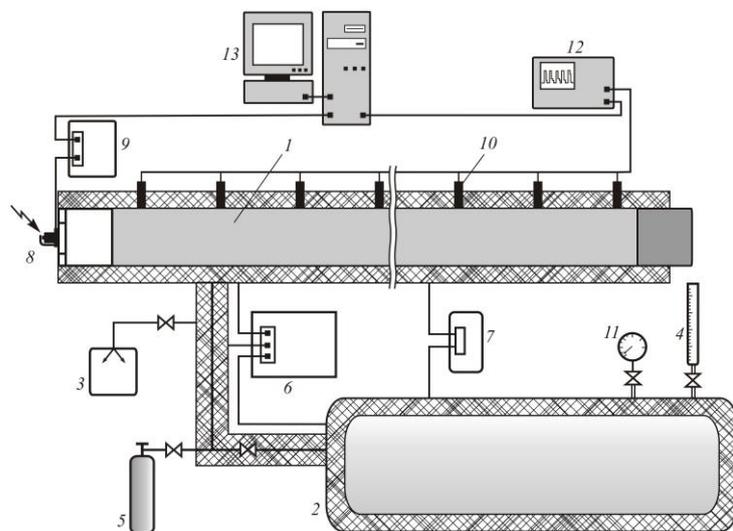


Figure 1. Experimental setup. 1 — detonation tube, 2 — evaporation (mixing) chamber, 3 — vacuum pump, 4 — *n*-heptane batcher, 5 — oxygen, 6 — heater power supply, 7 — temperature control, 8 — spark plug, 9 — spark plug power supply, 10 — ion current sensors (22 unit, distance between them 65 mm), 11 — manometer, 12 — oscilloscopes, 13 — PC.

A DDT distance and a time were determined by analyzing the *x-t* (distance-time) diagrams of the process, and the rate dynamics along the tube axis from a place of spark ignition.

30 cm heated section with soot foil that allow to determine the cellular structure and measure the detonation cell size λ was mounted at the end of detonation tube.

3 Results and discussion

The figure 1 plots the experimentally determined DDT distance and time as a function of initial pressure for stoichiometric ($\phi = 1$), lean ($\phi = 0.5$), and rich ($\phi = 2$) mixtures of heptane and oxygen at an initial temperature of 105-106⁰C.

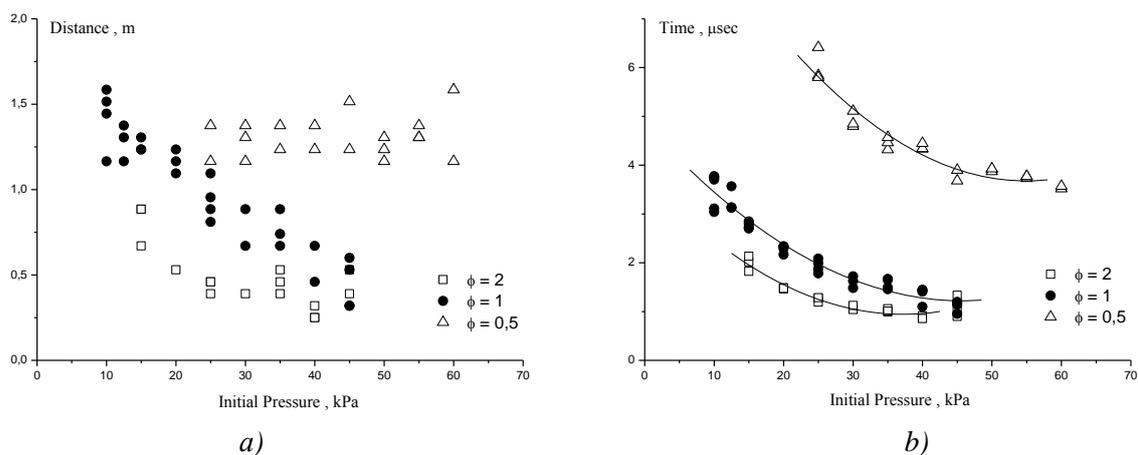


Figure 1. DDT distance (a) and time (b) in heptane/oxygen mixtures at initial temperature of 105-106⁰C.

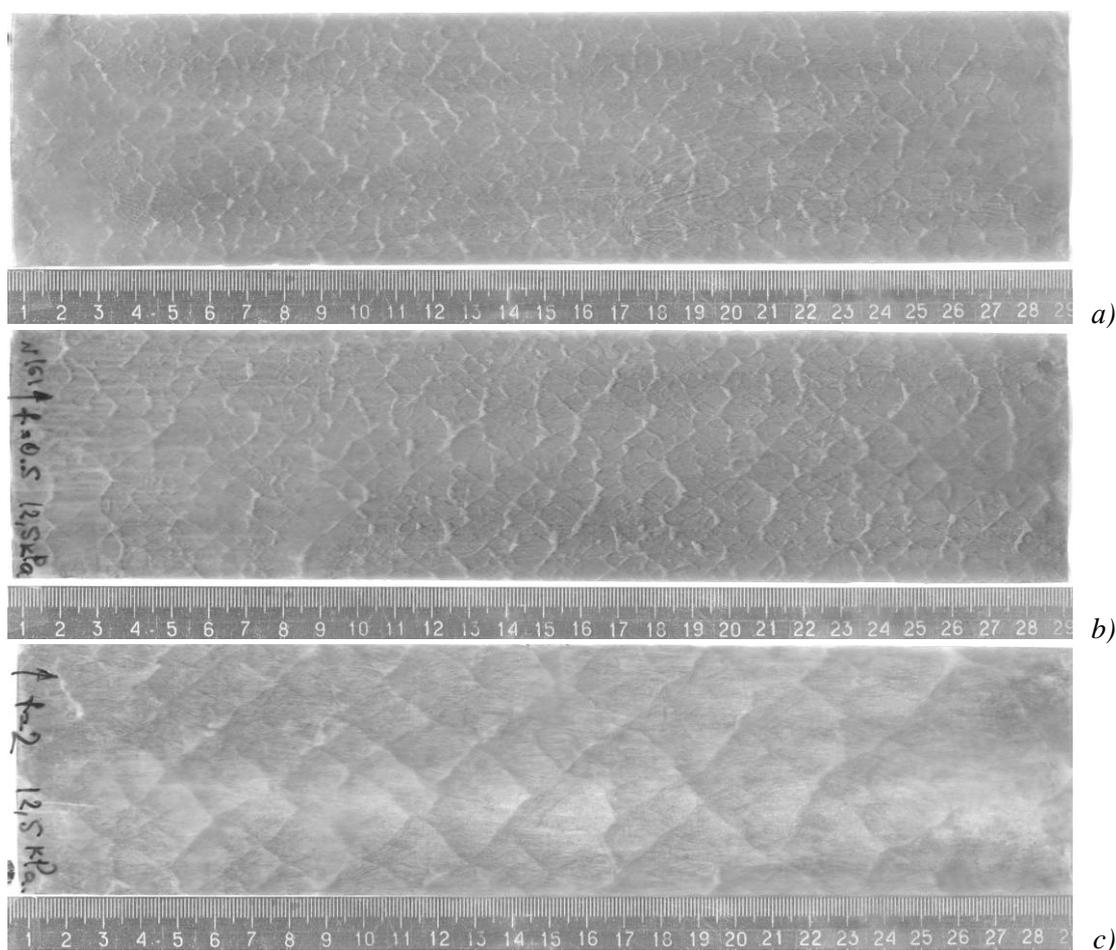


Figure 2. Typical smoke-foil pattern of cell structure observed for stoichiometric $\phi = 1$ (a), lean $\phi = 0.5$ (b), and rich $\phi = 2$ (c) mixtures of heptane and oxygen at initial temperature of 105-106⁰C and initial pressure 12,5 kPa.

The detonation structures that were recorded on soot foils for different equivalence ratio at initial temperature 105-106⁰C and initial pressure 12,5 kPa are presented on figure 2. Observed detonation structure is weakly regular and quite difficult to determine average detonation cell size. Nevertheless, for rich ($\phi = 2$) mixture average cell size at initial pressure 10 kPa and temperature of 105-106⁰C was found equal to 18 ± 2 mm, and 13 ± 1 mm at initial pressure 15 kPa. Imbert et al [1,2] report data, obtained on shock tube under normal initial temperature and also mentioned weakly regular cellular structure and difficulties of manual measurement of detonation cell size. The values of detonation cell size obtained in [1, 2] are approximately 6-10 mm for pressure 8-13 kPa that less than measured in present work. This can be explained by the fact that detonation created in high temperature and high pressure moving mixture, forced by strong incident shock wave. Calculated [3] size of detonation cell is about 0.8 mm at normal conditions at atmospheric pressure. But it's very difficult to verify this data in a real experiment.

It should be noted that it is difficult to achieve repeatability of results and figure 3 shows typical smoke-foils obtained for rich ($\phi = 2$) mixture of heptane and oxygen at initial temperature of 105-106⁰C and initial pressure 15 kPa. Even in one series of experiments (when we used one and the same mixture under one and the same temperature and initial pressure) results may differ greatly. Figure 4 presents x-t diagrams and velocity dependence along tube axe for several experiments presented on figure 3. It's clearly that velocity is stable and correlates well with calculated one, and DDT or overdriven detonation is not observed. Nevertheless, we obtain three absolutely different smoke-foil records (figure 3). Obviously, it's necessary to obtain a larger amount of experimental data to be sure that detonation cell size measurements are correct.

As conclusions to our work we will note the following. DDT times and distances as a function of initial pressure for stoichiometric ($\phi = 1$), lean ($\phi = 0.5$), and rich ($\phi = 2$) mixtures of heptane and oxygen at an initial temperature of 105-106⁰C and initial pressures 10-60 kPa were determined. It was shown that minimal DDT distance for our conditions was about 40 cm for stoichiometric ($\phi = 1$) and rich ($\phi = 2$) n-heptane/oxygen mixtures. For lean ($\phi = 0.5$) mixture this value about 1.2-1.3 m. Minimum DDT time was about 1.1-1.2 msec for stoichiometric and rich mixtures.

The influence of initial pressure on detonation cell size was examined. Obtained data can be useful to people who are engaged in modeling and calculation. But, considering irregular cellular structure it is necessary to obtain a larger amount of experimental data.

Present work is still in progress.

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References

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- [3] Vasil'ev A.A. (2009). Detonation properties of saturated hydrocarbons. Combustion, Explosion, and Shock Waves, Volume 45, issue 6, p. 708 - 715.

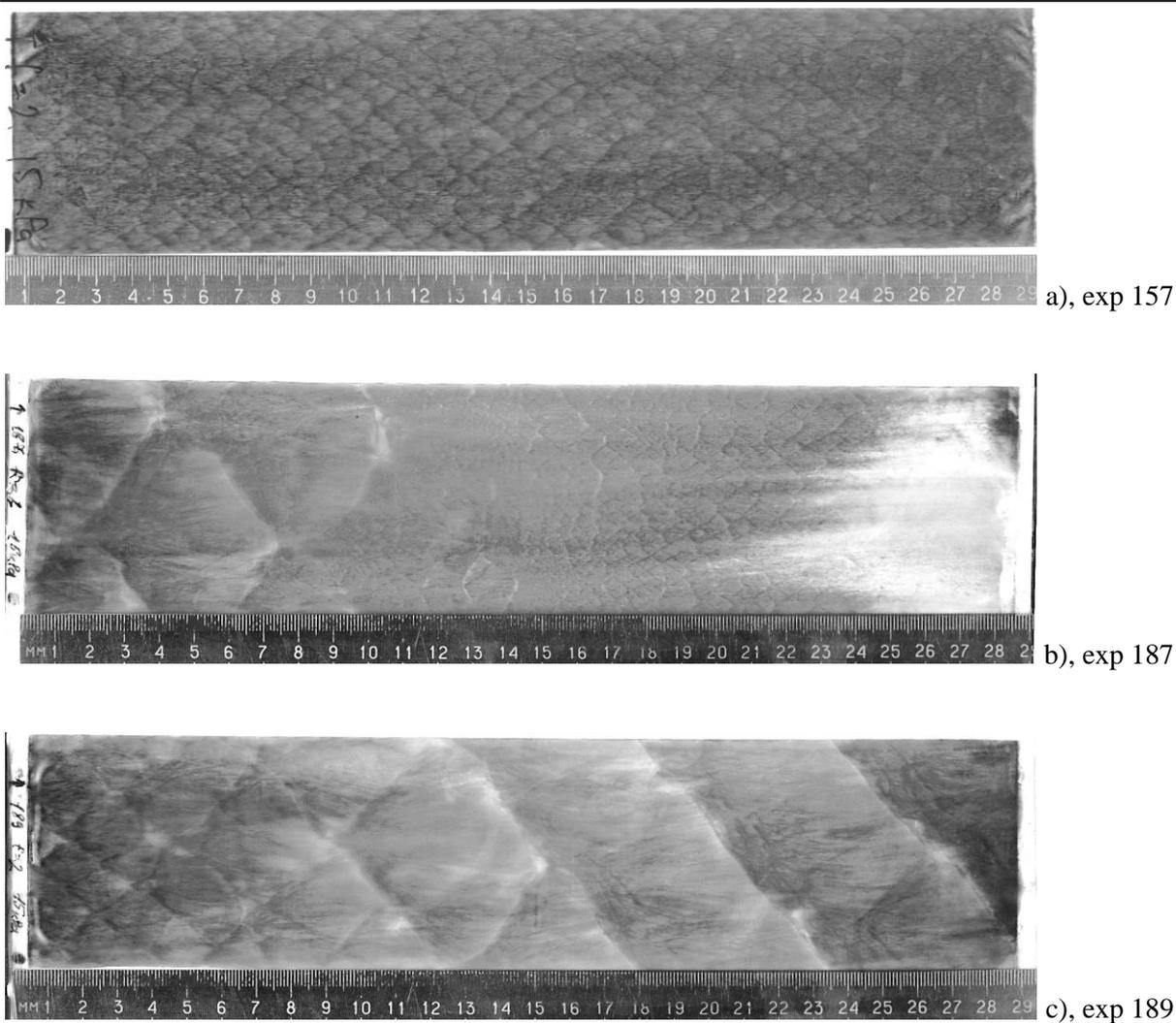


Figure 3. Typical smoke-foil patterns of cell structure observed for rich ($\phi = 2$) mixture of heptane and oxygen at initial temperature of 105-106⁰C and initial pressure 15 kPa.

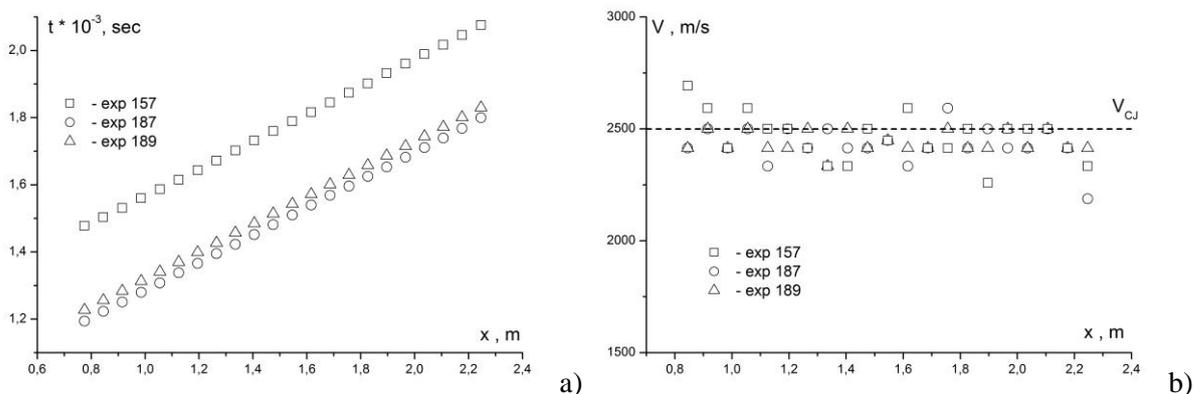


Figure 4. X-t diagrams (a) and velocity along tube axis (b) for rich ($\phi = 2$) mixture of heptane and oxygen at initial temperature of 105-106⁰C and initial pressure 15 kPa (experiments presented on fig 3).