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Decreasing the Predetonation Distance in a Drop Explosive Mixture by Combined Means

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In this work, a deflagration-to-detonation transition in drop mixtures of hydrocarbon fuel with air was experimentally detected for the first time. It is shown that a Shchelkin spiral and a new element, a coil of the tube, significantly decrease the detonation initiation energy and the predetonation distance.

There are several ways to decrease the predetonation distance in gaseous explosive mixtures. Laffitte [1, 2] experimentally demonstrated that a decrease in the tube diameter and an increase in the initial pressure of an explosive mixture decrease the predetonation distance. Shchelkin [3] revealed that the aerodynamic conditions in the channel play a leading role in the deflagration-to-detonation transition. He showed that, if an obstacle in the form of a wire spiral (a Shchelkin spiral) is placed in the channel, the predetonation distance decreases considerably. Shchelkin and Sokolik [4] detected a decrease in the predetonation distance after preliminary heat treatment of fuel. Brophy *et al.* [5] showed that the predetonation distance in the case of ignition of a mixture by a nanosecond corona discharge in combination with a Shchelkin spiral is smaller than that in the case of ignition of a mixture by an arc discharge. We previously [6] proved experimentally that the predetonation distance can be significantly decreased by accelerating a weak shock wave by a traveling forced ignition pulse, i.e., using an idea that was first proposed by Zel'dovich and Kompaneets [7].

Unlike the deflagration-to-detonation transition in gaseous mixtures, the deflagration-to-detonation transition in drop mixtures of liquid fuel with air (oxygen) is virtually unstudied. In available experimental studies [8–10], heterogeneous ("drop") detonation was initiated by strong sources: a shock wave [8], gas detonation [9], or an explosive charge [10]. Earlier [11, 12], we initiated detonation of sprays of liquid fuel in air by one or two electric discharges. In drop mixtures of liquid fuel with gaseous oxygen, a deflagration-to-detonation transition was observed by Pierce and Nicholls [13], who reported that the predetonation distance was 20–100 tube calibers long. Data on experimental observations of deflagration-to-detonation transitions in drop mixtures of hydrocarbon fuels with air are unavailable in the literature. In the context of increasing interest in the practical use of detonation combustion in aircraft engines and power engineering [14], it is topical to study a deflagration-to-detonation transitions in drop mixtures of hydrocarbon fuel with air.

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The purpose of this work was to use combined means for attaining a deflagration-to-detonation transition and decreasing the predetonation distance in drop hydrocarbon–air mixtures.

Previously [11, 12], we studied detonation initiation in the flow of a drop *n*-hexane–air mixture in a (1.3 ± 0.1)-fold excess of fuel under normal conditions in a 1.5-m-long tube 51 mm in diameter, which was equipped with a full-flow air-assist atomizer at one end and a detonation arrester at the other. Ignition was performed with a high-voltage electric discharger placed at a distance of 60 mm from the atomizer nozzle, where the average size of drops in the jet was 5–6 μm. Beginning with a discharge energy of $E \sim 3300$ J, a direct initiation of detonation took place in the mixture, which propagated at a velocity of 1700–1800 m/s. At a discharge energy in the range $1100 < E < 3300$ J, a decaying shock wave and a decelerated flame were observed [11, 12]. At $E < 1100$ J, there was a certain acceleration of the flame along the tube but pressure waves propagated at velocities of no more than 400–450 m/s.

To decrease the detonation initiation energy, we performed similar experiments with drop *n*-hexane–air and *n*-heptane–air mixtures in tubes of smaller diameters (36 and 28 mm) than those studied earlier [11, 12]. In addition, to enhance the turbulence in the jet of the drop mixture coming from the atomizer, a 600-mm-long Shchelkin spiral wound from a steel wire 4 mm in diameter at a spiral pitch of 18 mm was placed in the tube. At a low ignition energy of 130–240 J, the velocity of the shock wave leaving the spiral reached 900–1000 m/s. A change in the spiral wire diameter or in the spiral pitch or length did not lead to any significant changes in the characteristics of the obtained shock waves at such ignition energies.

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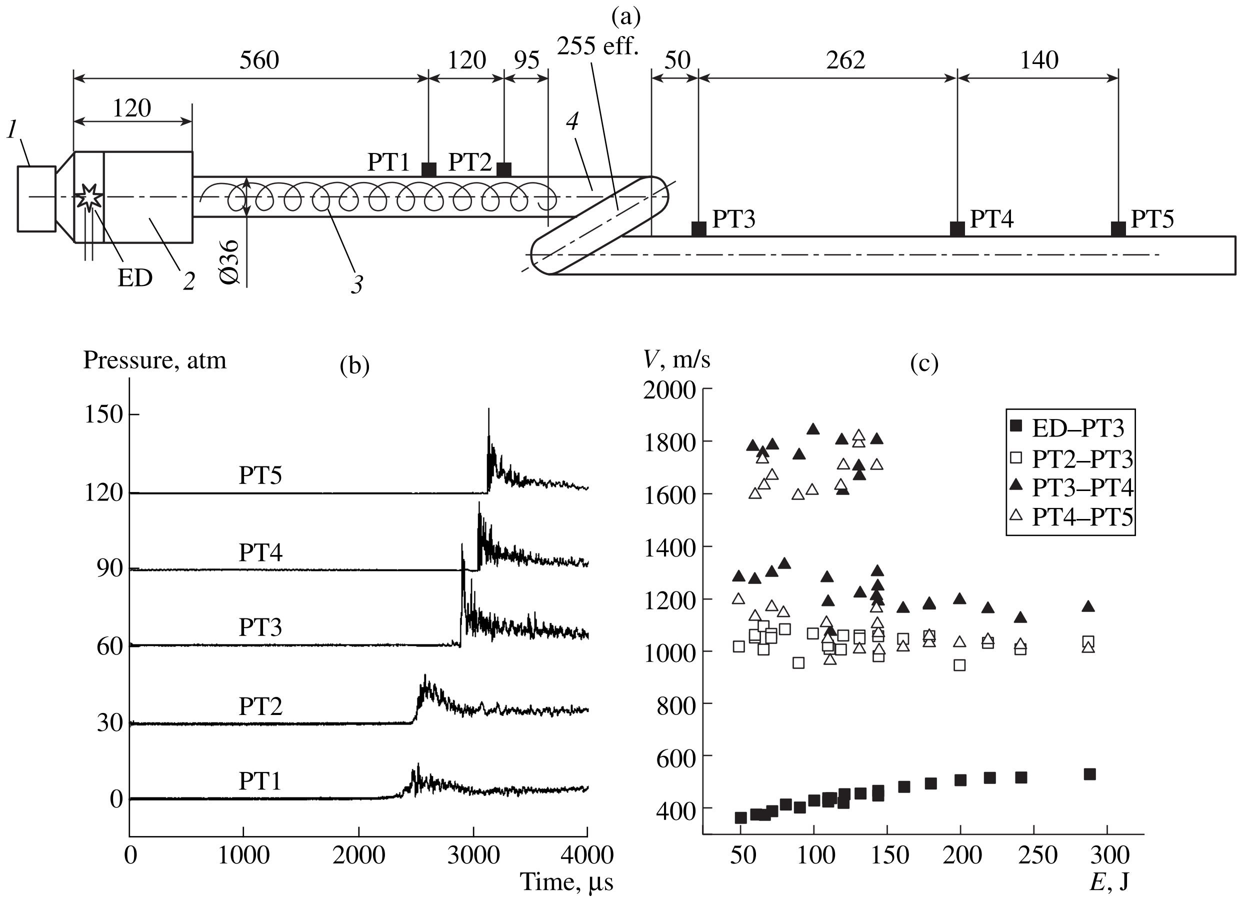

Fig. 1. (a) Schematic of an explosion tube 36 mm in diameter with a new element—a coil, (b) the pressure profiles recorded by transducers PT1–PT5 in an experiment with an ignition energy of $E = 60$ J, and (c) the measured shock wave velocity in a drop *n*-hexane–air mixture over different measurement segments vs. ignition energy.

To further enhance the obtained shock wave, a new element—a coil of a tube—was placed downstream of the section with the Shchelkin spiral. Figure 1a presents a schematic of the explosion tube 36 mm in diameter with atomizer *1*, discharge chamber *2*, electric discharger ED, Shchelkin spiral *3*, and tube coil *4*. Piezoelectric pressure transducers PT1–PT5 were used to record the profiles of pressure waves in the tube and to determine the velocities of these waves. We expected that the curvilinear reflecting surfaces in coil *4* might lead to gas-dynamic "focusing" of a shock wave and to detonation. Note that the focusing effect of coils of explosion tubes in reactive media has not hitherto been studied, although the phenomenon of focusing of shock waves in straight tubes after reflection from a nonplane end wall has long been known [15].

Figure 1b shows the pressure profiles recorded by transducers PT1–PT5 in an experiment with an ignition energy of $E = 60$ J. Unlike experiments in a straight tube, here, transducer PT3 at the outlet of the coil detected a detonation wave. The detonation emerges within the coil at a distance of about 1 m from the discharger (about 28 tube calibers). The detonation wave propagates to the end of the tube at a velocity of 1750 ± 20 m/s. Figure 1c presents the results of measuring the velocity *V* of pressure waves in this set of experiments over four measurement segments: between the discharger and transducer PT3 (ED–PT3), between transducers PT2 and PT3 (PT2–PT3), between transducers PT3 and PT4 (PT3–PT4), and between transducers PT4 and PT5 (PT4–PT5). It is seen that, at ignition energies from 60 to 144 J, a number of experiments detected detonation at the outlet of the coil. Detonation occurred randomly with a frequency of about 50%. It is of interest that detonation never emerged at higher ignition energies (144–300 J). Probably, this is because a cumulating pressure wave (in the terms of Shchelkin) is formed outside of the coil at high ignition energies.

To further decrease the ignition energy sufficient for initiating a detonation explosion within the coil, we used the tube of a smaller diameter, 28 mm. Figure 2a presents a schematic of an experimental setup in which the minimal energy (30 J) of initiation of detonation of drop *n*-hexane–air mixtures was attained. The setup consisted of atomizer *1*, discharge chamber *2*, electric discharger ED, Shchelkin spiral *3*, tube coil *4*, ioniza-

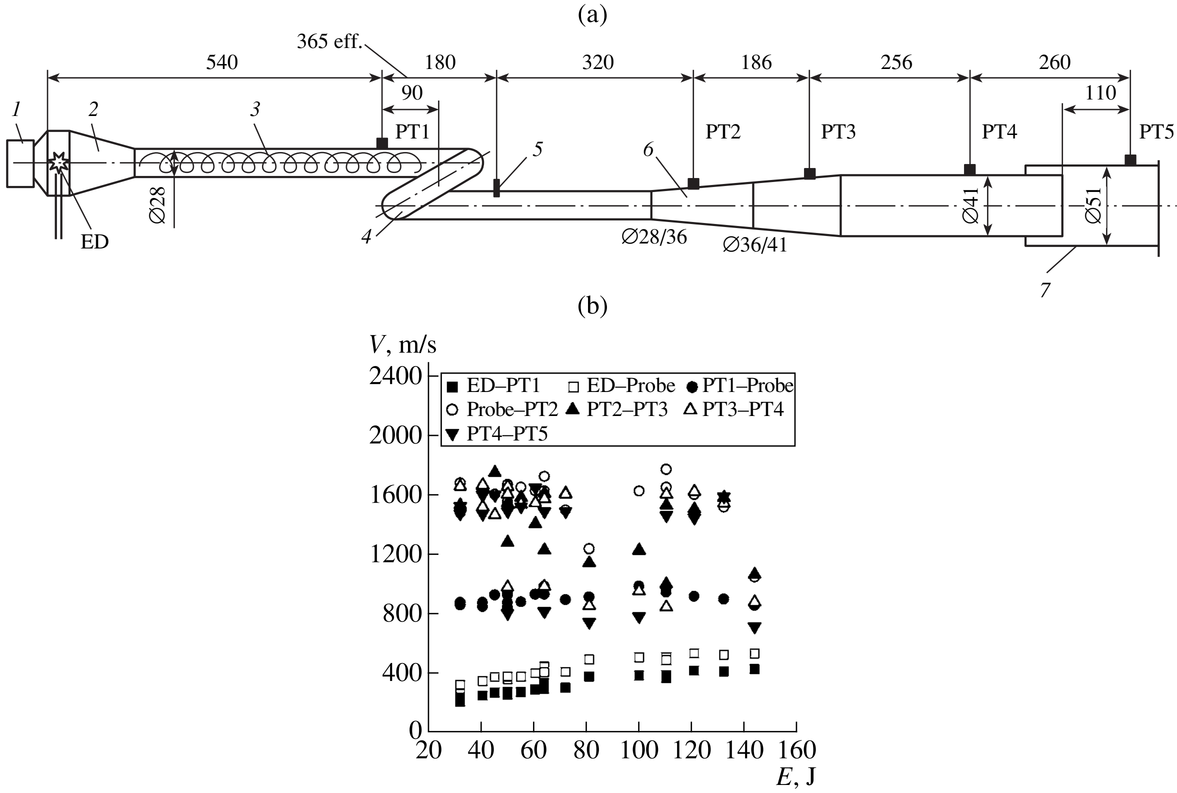

Fig. 2. (a) Schematic of an explosion tube 28 mm in diameter with a coil and a transition section to a tube 51 mm in diameter and (b) the measured shock wave velocity in a drop *n*-hexane–air mixture over different measurement segments vs. ignition energy.

tion probe *5*, two tapered sections *6*, and main tube *7* of a diameter of 51 mm. The pressure profiles recorded on this setup show that detonation emerged within the coil and propagated into the tube 41 mm in diameter and then into the main tube. At ignition energies from 30 to 50 J, detonation in the coil occurred at a high frequency and always propagated into the main tube (Fig. 2b). At ignition energies from 50 to 130 J, detonation did not always propagate into the main tube. At ignition energies from 130 to 300 J, no detonation was observed. Analogous results were obtained for drop *n*-heptane–air mixtures.

Design changes in the setup shown in Fig. 2a (changes in the shape of discharge chamber *2*, the length of spiral *3*, the shape of coil *4*, the length of the section of the tube from the end of the spiral to the coil, or even the length of the section of the tube to the tapered sections) led to changes in the observed explosion dynamics. A high reproducibility of experiments on initiation of detonation in the coil became possible owing to careful optimization of the setup design.

Thus, the replacement of the straight explosion tube 51 mm in diameter [11, 12] by the combined tube (Fig. 2a) decreased the energy of initiation of detonation of drop *n*-hexane–air and *n*-heptane–air mixtures by two orders of magnitude: from 3300 to 30 J. In the experiments with the coil, an electric charge was used as a source of ignition of a mixture rather than a source of a strong initiating shock wave. Consequently, we were the first to detect a deflagration-to-detonation transition in drop mixtures of hydrocarbon fuel with air. The predetonation distance in the tube 28 mm in diameter turned out to be close to 1 m, i.e., to 36 tube calibers, and the total predetonation distance to the main tube 51 mm was diameter is 1.8 m. For comparison, we note that a deflagration-to-detonation transition in a gaseous propane–air mixture requires no less than 260 calibers for a straight smooth tube and more than 60 calibers for a straight tube with turbulence promoters in the form of regular obstacles [6].

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