Spontaneous Detonation in the Mixture of Initial Reagents with Hot Detonation Products

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Deflagration-to-detonation transition (DDT) and spontaneous detonation have been intensively studied in the past decades as processes accompanied by maximum destruction in industrial accidents [1-8]. Basic mechanisms are formulated in [7,8] which state that these are (*i*) large-scale energetic eddies found in the unburned gas in the turbulent pockets behind obstructions or ahead of flame jets, (*ii*) a sufficiently intense fine structure of turbulence required to enhance the mixing of hot combustion products with initial reagents in the above eddies, (*iii*) a gradient field of induction time in the turbulent pocket; this field is needed to bring about shock wave amplification by the coherent energy release [5, 6].

RFNC-VNIITF proposed the way and the facility, which are used to investigate these mechanisms "under the magnifying glass " [9, 10]. This paper reports first results on critical initiation energy for the mixture of the initial propane-air composition with hot detonation products as well as first observation results for spontaneous processes at TSD-01M facility in the variant when the main tube has open face-ends.

In the shock tube volume under investigation the facility (Fig. 1) creates the mixture of the initial propane-air composition with hot detonation products (HDP). Area of the above

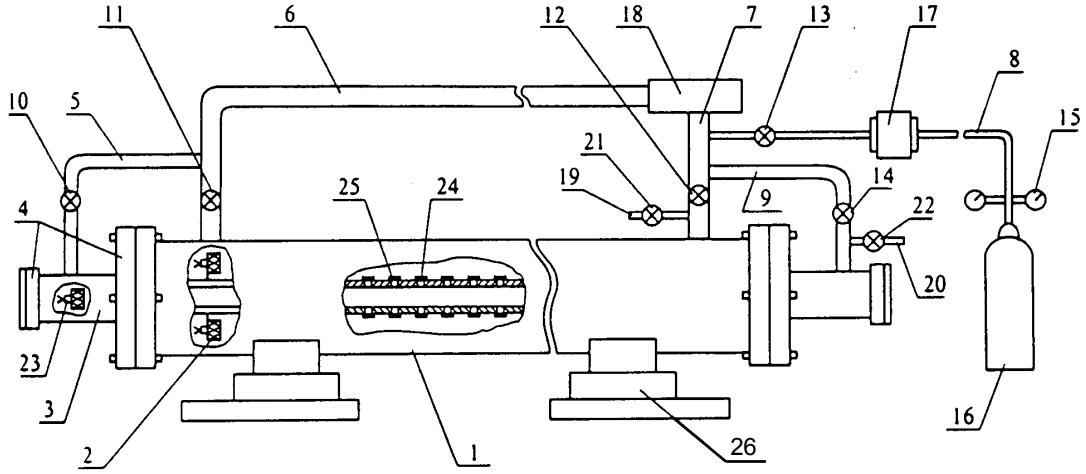

Fig. 1. TSD –01M facility (Tube of Spontaneous Detonation).
1-main tube; 2-detonation initiator (HE charge); 3-small tube for injecting hot detonation products; 4-sealing flanges (on the main tube flanges can be substituted by the 0.2 mm polyethylene film); 5÷9-tubes with valves 10÷14; 15-pressure regulator; 16-cylinder with propane; 17-gas meter; 18-fan; 19, 20-branch pipes with valves 21, 22 for the connection of mixture volume compensators; 23-initiator of detonation in a small tube; 24-holes in the small tube walls; 25-destructible orifice plates (optional); 26-support.

mixturein the left part of the tube is adjacent to the area of cold initial reagents in the right part. Processes are diagnosed by pressure gauges and photosensors as well as by the trace procedure of smoked surfaces. Hot products occur and are injected into the main tube of the facility when the initial propane-air composition is detonated in the small perforated tube. Methods used to calculate HDP concentration in the tube length are given in [10].

Flanges 4 (Fig.1) did not mount on the tube and its ends have closed by polyethylene films (0,2 mm) so as to be near to the open tube case. Detonation was force-initiated with 9 ms delay from the time of mixture initiation in the small tube (Fig. 2) in order to determine detonability of the mixture with hot detonation products in the facility main tube. A series of experiments was carried out to determine critical energy E_* of the direct initiation. The obtained value of E_* (19 J/sm^2) for the mixture with 8-5 vol % of hot detonation products is almost 2 times less than E_* (37 J/sm^2) for initial reagents. Part of such experiments registered quenching of detonation when it transits from the area with hot detonation products into the initial reagents. In all cases one registered ignition of initial reagents at the boundary of areas as well as flame acceleration with the subsequent deflagration flash and propagation of the complex "wave-flame" accelerating up to 850 m/s.

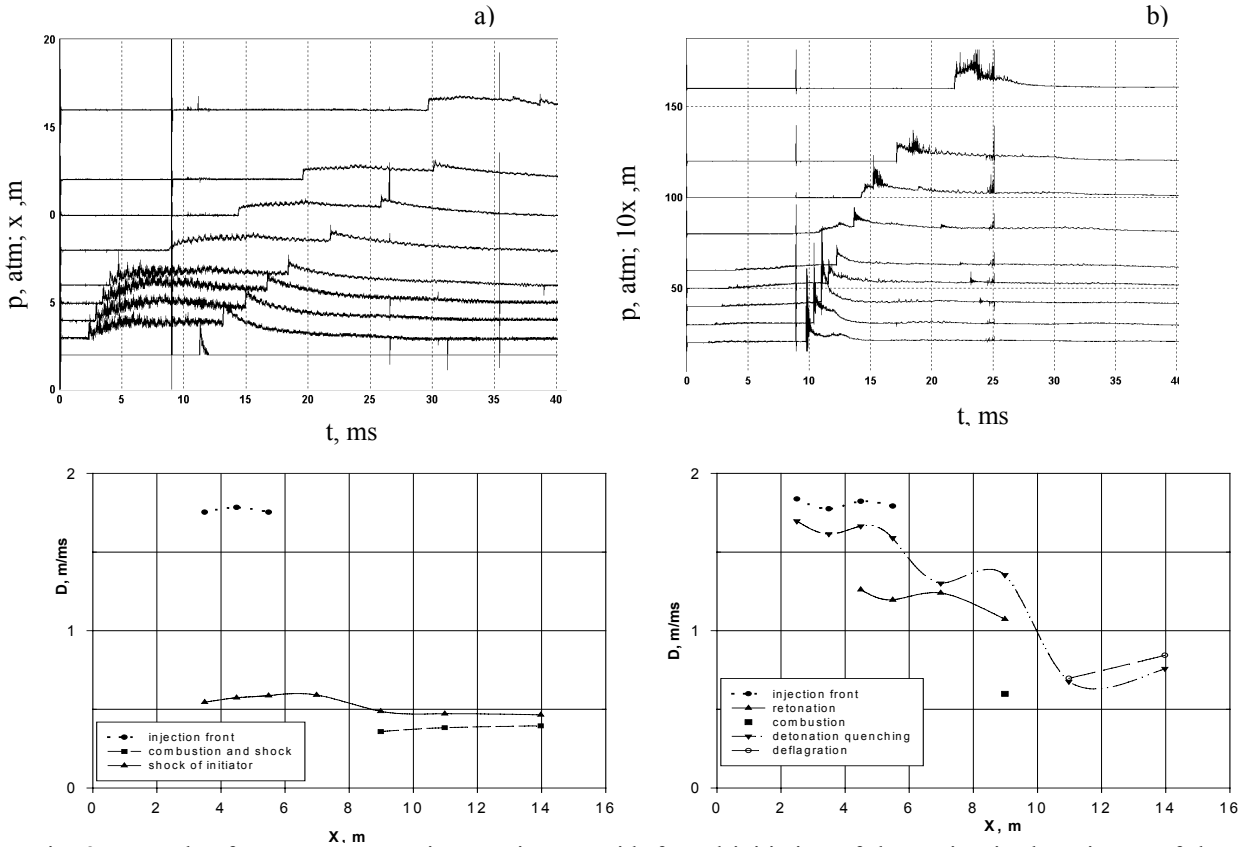

Fig. 2. Records of pressure gauges in experiments with forced initiation of detonation in the mixture of the propane-air composition with hot detonation products and dependencies of process velocities on the distance from the small tube face-end.

a) HDP injection, ignition of initial reagents (7 vol. % C_3H_8) at the boundary with HDP, shock wave acceleration from the boundary with HD, detonation failure by E=23 J/sm^2; b) HDP injection, ignition of initial reagents (5.8 vol. % C_3H_8) at the boundary with the area involving HDP, detonation in the mixture with HDP by E=28 J/sm^2, detonation quenching in the case of transition into initial reagents, accelerating deflagration in initial reagents.

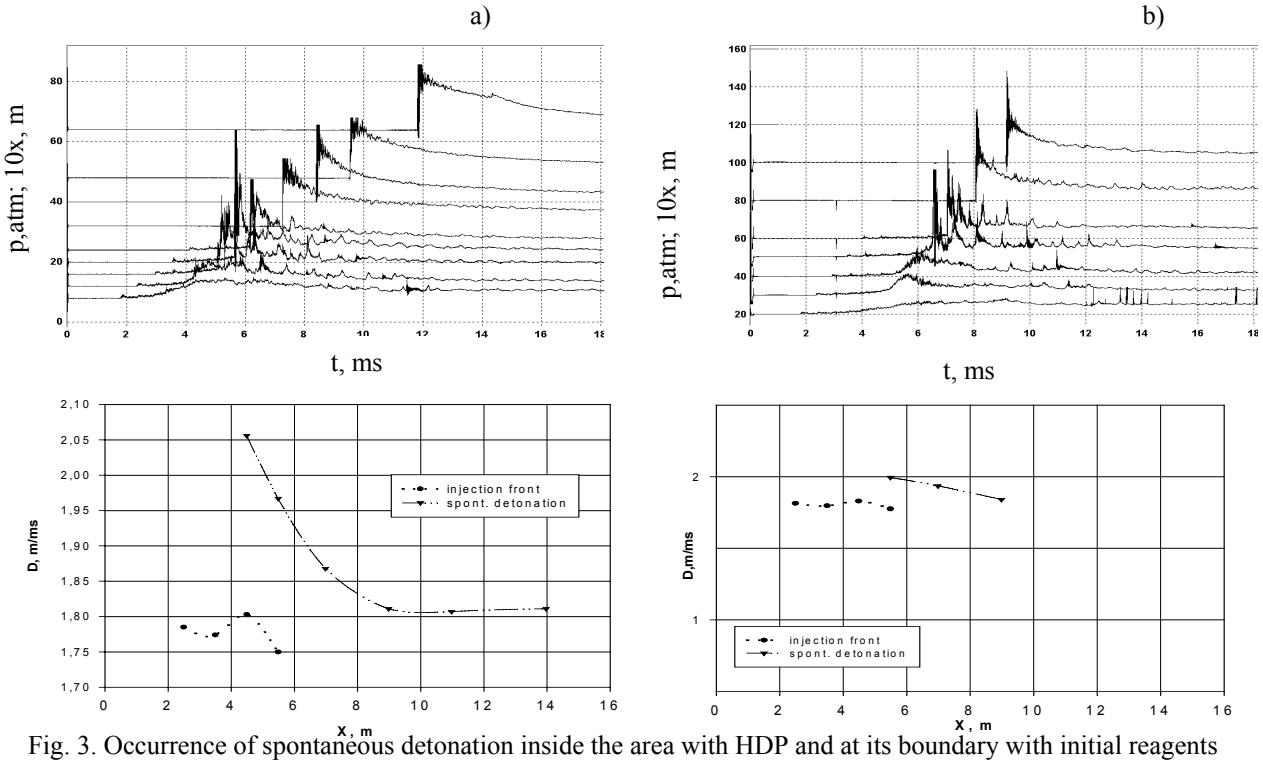

Fig. 3. Occurrence of spontaneous detonation inside the area with HDP and at its boundary with initial reagents (3.7 vol. % C_3H_8 to the left and 4.4 vol. % C_3H_8 to the right).
Sequence of events: HDP injection, occurrence and propagation of spontaneous combustion at superdetonation velocity, detonation occurrence against combustion, detonation propagating through initial reagents.

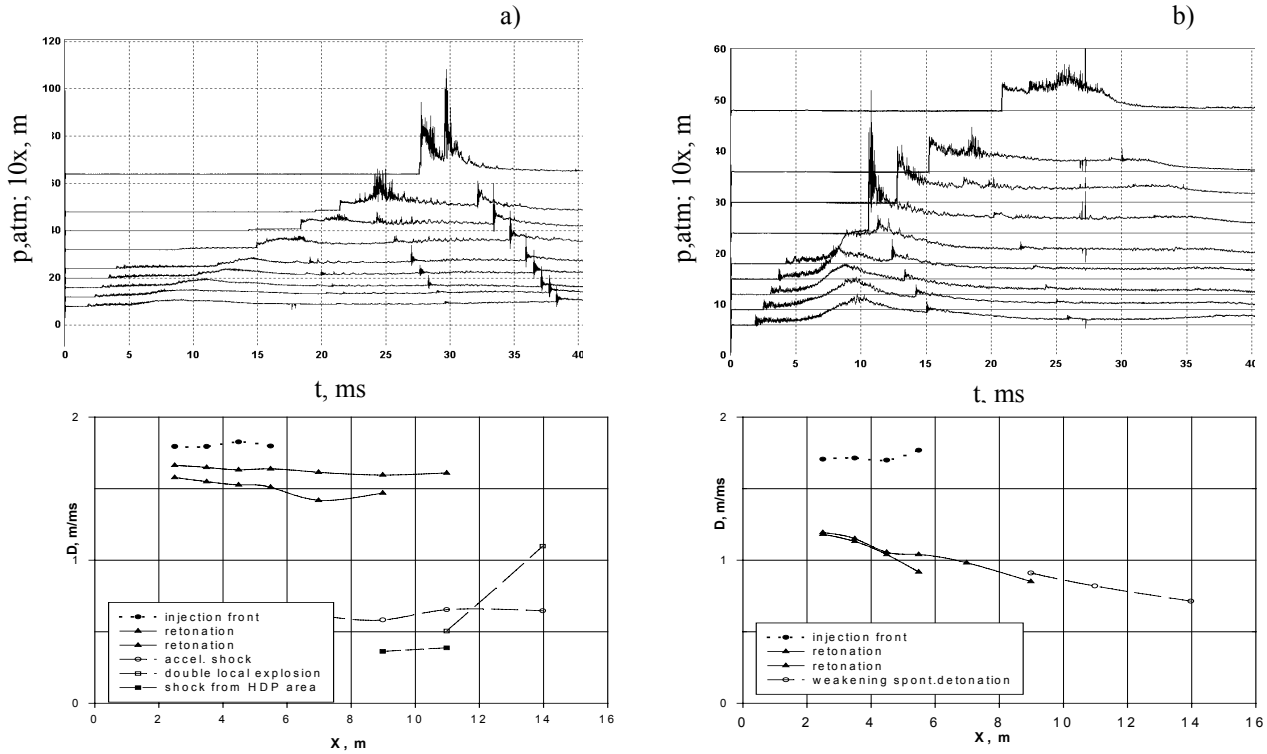

Fig. 4 Records of pressure gauges in the absence of spontaneous detonation in the area with HDP.
a) – classical DDT according to [1] – shock wave acceleration in initial reagents (4.9 vol. % C_3H_8) from the boundary with HDP and local explosion, retonation waves; b) – occurrence in initial reagents (3.3 vol. % C_3H_8) of spontaneous detonation against spontaneous combustion propagating in both directions and detonation quenching, retonation waves.

Mixture with hot detonation products was not force-initiated in the case of spontaneous detonation registration. Spontaneous detonation was observed both in the area with hot detonation products, and at the boundary of this area with initial reagents (Fig. 3). Detonation occurrence by the mechanism of the classical DDT [1] (Fig. 4a) with high-velocity retonation waves was observed in the area of initial reagents at spontaneous detonation absence in the area with HDP. In some experiments one observed a not taken place spontaneous detonation that terminated in deflagration at the velocity of 700 m/s (Fig. 4b).

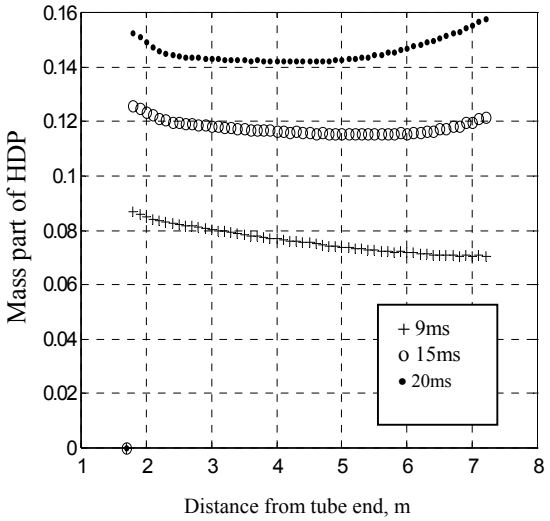

Fig. 5. Distribution of HDP mass concentration in length of the main tube for three instants of time. Initial composition– 4 vol. % C_3H_8.

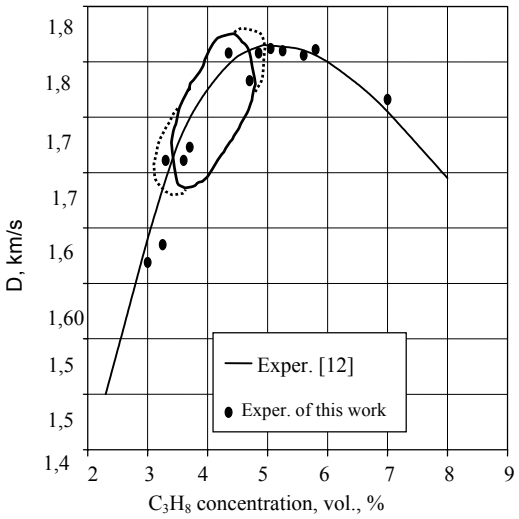

Fig.6. Experimental detonation velocities in initial propane-air compositions inside the small tube of TSD-01M facility in comparison with data from [12]. “Island ” of spontaneous detonation.

With used concentrations and the gradient of HDP concentration (Fig. 5) the “island” of spontaneous detonation, i.e. the concentration range (3.3 – 5 vol %) of propane in the initial composition where spontaneous detonation is realized with 1.7-3.1 ms delays from HDP injection onset (Fig. 6) is discovered.

Spontaneous detonation with great delays (30 – 45 ms) was registered in the small tube of the facility in the inversion variant of the facility operation when HDP were injected from the main tube into the small one. This corresponds to the creation of mixtures with high concentration of hot detonation products (up to 80 mass %).

Conclusions

1. Experimental results obviously confirm the leading role of the gradient high-turbulence area of the mixture with hot detonation products in the spontaneous detonation occurrence.
2. Detonability of the mixture with hot detonation products is significantly higher than that of initial reagents.
3. Spontaneous detonation occurs inside the area with hot detonation products or at the boundary with initial reagents within a narrow range of fuel concentration in

the initial composition and within a wide range of HDP concentrations, and this agrees with calculations [11].

4. Shock wave being formed at the boundary of the area with hot detonation products, when they are injected, does not directly initiate detonation and causes only deflagration flash within the deflagration time in the case of acceleration.
5. Deflagration in initial reagents accelerates up to high (~ 850 m/s) velocities during the observation time.

Acknowledgements

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