The Influence of Inert Nanoparticles on DDT in Hydrogen-Air Mixtures

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1 Introduction

The phenomenon of transition to detonation in the presence of non-gaseous additives like a suspended fine powder is both of practical and fundamental importance. The main attention in the investigation of the influence of the inert particles on the fast flame propagation and detonation initiation was paid previously on the determination of the conditions when the particles can promote these processes [1, 2]. The possibility of the quenching the explosion processes by dust particles was demonstrated in [3-5]. The influence of inert dust on the velocity of a steady detonation and detonation limits was investigated in [4, 5]. It was established that depending on the size of the dust particles they could influence on the detonation limits in two different ways. The smaller particles with 14 μm in diameter had no influence on the detonation propagation limits at low particle concentrations, whereas the increase of the particle diameter up to 450 μm caused a broadening of the lean limit of detonation propagation at some particle concentrations. The main conclusion of [4] is that the inert particles added to a combustible gaseous mixture can enhance detonation, or preclude detonation, depending upon the particle size and concentration. From the other hand in the case of channels equipped by the regularly spaced obstacles the phenomenon of deflagration-to-detonation transition (DDT) in gaseous mixtures was investigated rather extensively. The aim of the present work is the experimental investigation of the influence of inert nanoparticles suspended or layered in the obstructed volume on DDT in hydrogen-air mixtures.

2 Experimental details

The experiments were performed in 141-mm detonation tube of 4.24 m in length. The obstacle arrangement in the form of equidistantly placed orifice rings was chosen with the following parameters: distance between the adjacent rings $L \cong D_0$ (D_0 = 141 mm), diameter of the orifice d = 90 mm, outer diameter of the ring D_1 = 130 mm, thickness of a ring h = 10 mm. Blockage ratio calculated by the formula BR = $1-(d/D_0)^2$ = 0.59. The obstacle arrangement is consists of totally 13 rings. The fourteenth orifice ring with an inner diameter of 110 mm has no gap between ring and the tube wall and is part of the 0.3-m long test section, which is mounted between the obstacle-filled section and the tracking section. The overall length of the obstacle arrangement is 2.04 m. The obstacles-filled part and the test section are the most extensively instrumented, including multiple holes for pressure and ionization gauges. The tracking section is placed downstream of the obstacles-filled section. It has instrumentation ports for monitoring the development of explosion processes downstream of the obstacles-filled part of the tube. The length of the tracking section (including test section) is 2.2 m

Mixtures of 19%-30% hydrogen in air at initial pressure of 1 bar were studied. Nanoparticles of AEROSIL with the particles size of 12.3 nm (A_12) and for comparisoin the corundum with average particles size of 12.3 µm (C_12) were choosen as dust materials for investigation. The dust suspension is produced in two different ways. The first technique is the dispersion of the dust before ignition in the whole volume of the obstructed part of the tube. For this purpose the technique described in [6] is used and in this case the flame accelerates in the premixed dusty mixture. The second way is to deposit a dust layer in a controlled manner on the bottom of the tube in the obstacles-filled part. In this case, the dust dispersion will be generated by means of a precursor shock wave [7]. The volume of the dust layer was varied from 0.0001 m^3 to 0.004 m^3. The dust layer was put into the obstacles-filled part of the tube with the help of a special loading trough. Before the experiment the trough was filled by a dust material. Then it was inserted into the tube and overturned to place a desirable amount of dust onto the bottom of the obstacles-filled part of the tube.

3 Results and discussion

The low concentration limit of DDT in the dust free obstacle arrangement is given by 19% hydrogen in air. At 19% hydrogen in air mixture detonation starts just downstream the obstructed part. As the hydrogen content increases the detonation run-up distance decreases and quasi detonation regimes takes place inside the obstructed part.

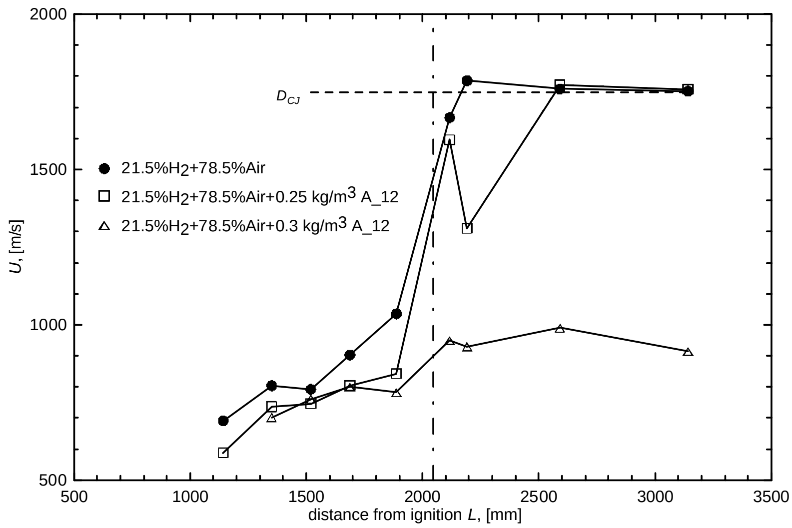

Fig.1

Figures 1 and 2 represent the evolution of the pressure front velocity for the near limit case of 21.5% H_2 in air mixture in the presence of two kinds of dust particles that differs from each other by the value of particle diameter. In all of these figures the horizontal dashed line gives the C-J value of the detonation velocity of the considered mixture. The vertical dashed-dotted line shows the end of the obstacles-filled part. As it is seen from Fig. 1 even a small concentration of 0.3 kg/m^3 of dust A_12 is sufficient for the quenching of the DDT process. If the dust material A_12 is substituted by the material C_12 the critical concentration to suppress DDT raises up to 1.3-1.8 kg/m^3 as it follows from Fig. 2.

For the most sensitive mixture of 30% H_2 in air the detonation is successfully initiated at dust suspension concentration of A_12 up to 4 kg/m^3. The suppression of the DDT process is observed at concentration of 4.67 kg/m^3.

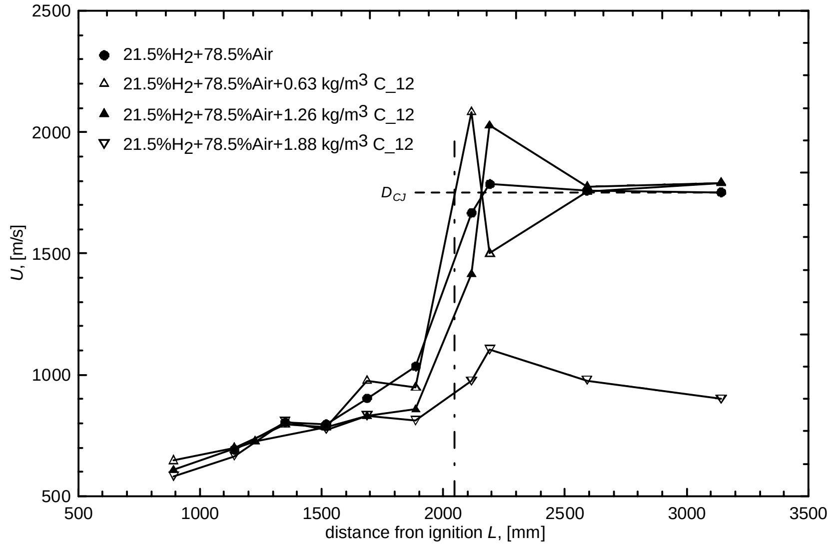

Fig. 2

The dust layers influence on the transition to detonation in the same manner as the dust suspension. Nevertheless the critical amount of dust material in the layer, which is necessary to suppress DDT, is significantly higher than in the case of the dust suspension. For example the transition to detonation in a 22%H_2 in air mixture does not occur for an amount of dust A_12 of 258 g/m. This amout of dust deposited as a layer corresponds to the volume concentration of dust about of 16.5 kg/m^3. In the case of dust suspension of A_12 and for a mixture with close sensitivity (21.5%H_2 in air) the critical concentration is not more than 1.88 kg/m^3 (see Fig. 1).

The experiments with dust layers were restricted to the maximum value of 258 g/m since in this case the overall bulk of the dust material (A_12) occupies a volume of 4 liters that becomes comparable with the volume of the obstructed part of the tube (approx. 30 liters). To examine the influence of the inert porous layer on shock wave followed by the accelerated flame the experiments with the layers of equivalent volumes (depthes) but consisting of the dusts with different sizes of the particles were performed using mixture of 22% hydrogen in air. The particles with diameters of 12 nm, 12.3 µm, and 0.25-0.5 mm were used. It was established that in this case the size of particles slightly influence on the velocity of leading shock wave at the exit from the obstructed part of the tube. The value of this velocity is 880 m/s for particles of 0.25-0.5 mm, and it is 820 m/s and 800 m/s for the particles of C_12 and A_12 correspondingly. However the detonation initiation takes place only in the case of the layer of 0.25-0.5 mm particles.

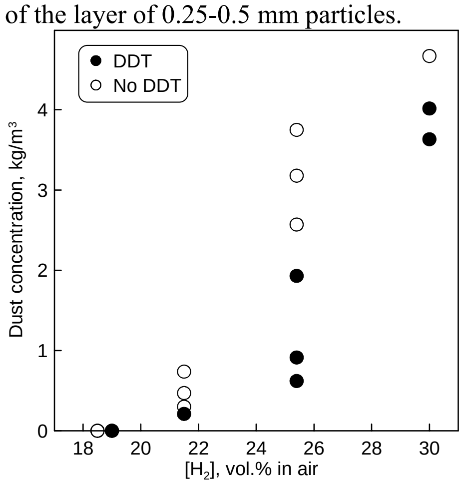

Fig. 3

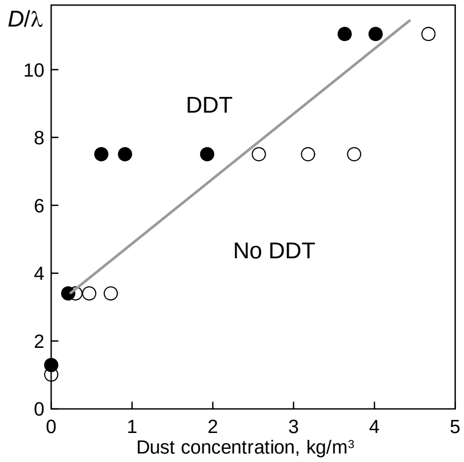

Fig. 4

The diagrams presenting the concentration limits of the DDT in the presence of an inert dust particles suspension is shown in Figs. 3, 4. Figure 3. compiles the results of experiments with DDT and no DDT for the case of dust material of A_12 in terms of dust concentration vs. hydrogen volume fraction in air. This diagram gives clear evidence on the substantial increase of the critical dust concentration with the increase of the hydrogen concentration in the range between 19%H_2 in air and 30%H_2. A suitable measure of the sensitivity of a combustible gaseous mixture is the detonation cell width. Figure 4 represents the results of experiments in terms of the ratio of the hole diameter of a ring in the obstacle arrangement (D = 90 mm) to the detonation cell width of corresponding hydrogen –air mixture λ. As it is shown in Fig. 4 the boundary between DDT and no DDT can be approximated by a roughly linear dependence.

4 Conclusions

The performed experiments revealed that there exists a boundary between DDT and no DDT that unambiguously is associated with the concentration of dust particles. The adequate description of this boundary requires a close consideration of the properties of flame-shock packets in the presence of inert dust additives. The extinguishing capability of both the dust suspension and the dust layer increases as the particle diameter is reduced. It was shown that the use of the dust suspension instead of the layer reduces the overall amount of dust material that is sufficient for the quenching of DDT of about 10 times.

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