Flame - shock wave dynamic studies at DDT in diluted stoichiometric acetylene-oxygen mixtures

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1 Introduction

The deflagration to detonation transition is a complicated process that has attracted scientists' attention for many years. Today there are a lot of experimental and theoretical materials on this topic, but researches in this field are still actually. This is due to the attempts to use a detonation in different technologies and energetic [1]. In the result of the development of the computer technology and computational methods the number of theoretical works and their complexity are growing. These data need to be verified. That is why the experimental studies of DDT are still important.

Significant impact on the formation and characteristics of the detonation wave has a flame acceleration following the leading shock wave in the gas [2, 3]. Besides conventional measurement techniques, different optical measurement techniques (the schlieren techniques, the laser-induced fluorescence) [2, 4, 5] are using to study and visualize this phenomenon. They are useful, but obtained information is usually two-dimensional and line-of-sight integrated. In this paper the experimental studies of DDT in a stoichiometric acetylene-oxygen mixture with 70 % of argon dilution and with 60 % of nitrogen dilution at different initial pressures are presented. Simultaneous registration of the locations of reaction zone near the wall in four directions along the tube and the additional pressure control at the same cross-sections provide the quantitative data on dynamics of the shock wave and the flame velocities, the spatial flame shape, the length of the induction zone between the shock wave and the flame front [6]. As the result the characteristic values of these parameters and the features of the process were determined.

2 Experimental setup

The experiments were carried out in the calibrated smooth-walled ($R_a \leq 0.4$ μm) round stainless steel detonation tube with inner diameter of 0.04 m and total length of 5.55 m (Figure 1).The combustion was initiated at the end wall of the detonation tube by the standard automobile spark plug. The ignition energy was about 0.8 mJ. The distance between the ignition point and the first measuring cross-section was 2.776 m. The test section of the detonation tube with 40 ion current and 5 high frequency pressure sensors

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was used to study the spatial flame shape, local flame and shock wave velocities, and the distance between the leading shock wave and flame front at different stages of deflagration to detonation transition. The measuring cross-sections of the tube were arranged as it is presented in Figure 1. The total number of measuring cross-sections was ten with the distance of 0.06 m between them. Each measuring cross-section was consisted of four ion current sensors and additionally five cross-sections (1, 3, 5, 7 and 10 in Figure 1) also had pressure sensor. Thus, the velocity evolution and the spatial flame structure had been carefully studied over the length of 0.54m.

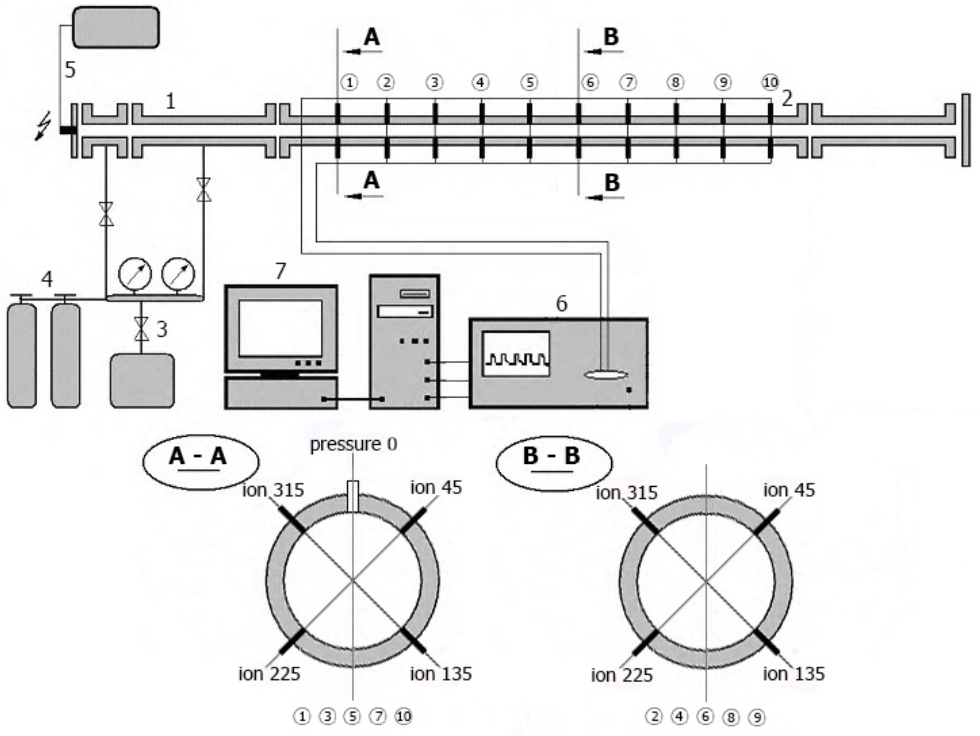
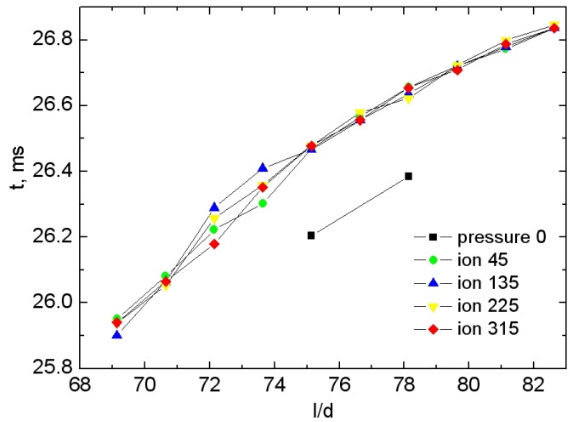


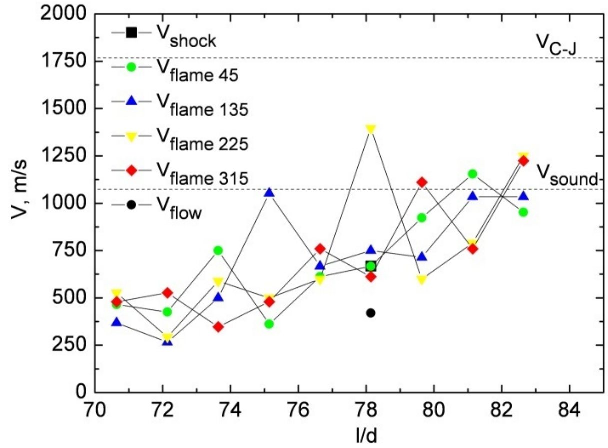
Figure 1. Experimental setup: 1 – detonation tube; 2 – test section with ion current and pressure sensors; 3 – vacuum pump; 4 – test gas; 5 – ignition unit; 6 – digital oscilloscopes; 7 – PC.

Stoichiometric acetylene-oxygen mixtures with 70 % of argon dilution and with 60 % of nitrogen dilution were used as a test gas. The test gas mixtures were prepared by the method of partial pressures. Post-shock gas parameters were calculated by the shock adiabatic curve, assuming "frozen" chemistry, and by the temperature dependence of heat capacity obtained from shock wave velocity measurements at different locations along the tube.

3 Results and discussion

The study of DDT in the stoichiometric acetylene-oxygen mixture with 70 % of Ar dilution at initial pressure from 20 to 35 kPa; and with 60 % of N_2 dilution at initial pressure from 19 to 50 kPa was carried out. In Figures 2, 3 the typical behavior and parameters of shock wave - flame dynamics at different pressures are presented.





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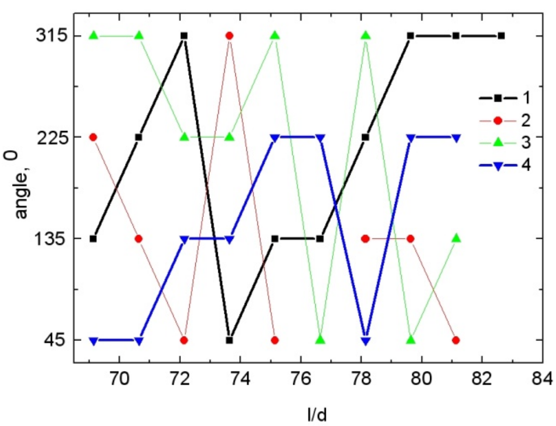

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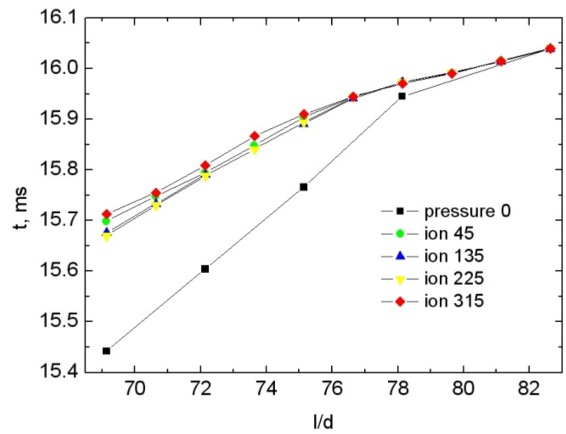
Figure 2. DDT in a stoichiometric acetylene-oxygen mixture with 70 % of argon dilution at 20 kPa: x-t diagram (a); local velocities of the flame, shock wave, flow behind the shock wave, $V_{C\text{-}J}$ and sound velocity of combustion products (b); the order of local flame arrivals at different peripheral locations in measuring cross-section (c)

At the beginning of the test section the registered extension of the flame along the tube, i.e. the distance between leading and remote edge of the flame, was maximal. These values in our experiments were 0.073and 0.172 m for mixture with Ar and N_2 respectively. They were calculated by multiplying the difference in arrival time between remote and leading edges of the flame by mean local velocity. Thus, the flame extension was near 1 – 2 tube diameters for mixture with Ar and near 1.5 – 4 tube diameters for mixture with N_2.

In the study we also tried to measure the induction zone length, but it was failed to do in our experiments for selected gas mixtures. We accurately registered the leading shock wave and then the slow increasing in pressure. The compression waves generated by the flame front did not turn into the enough intensive shock wave that we could observe before the onset of DDT. So we measured the distance between the leading shock and flame fronts. The maximal values of these distance, i.e. the distance between the leading shock wave and remote edge of the flame, was 0.413 and 0.347 m for mixture with Ar and N_2 dilution respectively, that was near 10 and 8.5 tube diameters. These values were calculated by multiplying the difference in arrival time between the remote edge of the flame and the leading shock wave by the flame velocity. During the flame acceleration along the tube this distance had significantly decreased. At the last cross-section before the onset of DDT it attained the minimal value of 0.068 and 0.048 m for mixture with Ar and N_2dilution respectively.



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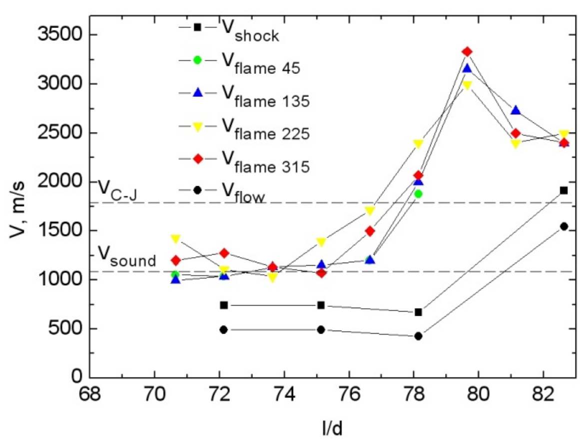

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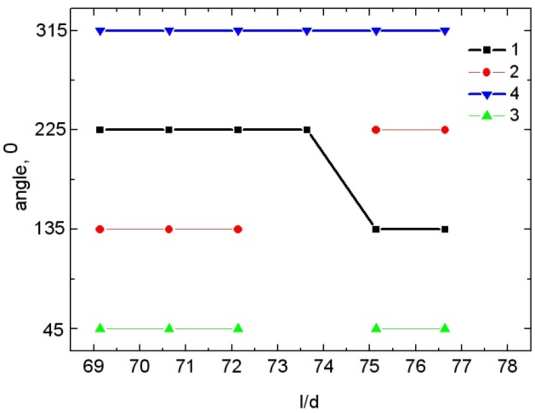

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Figure 3. DDT in a stoichiometric acetylene-oxygen mixture with 70 % of argon dilution at 35 kPa: x-t diagram (a); local velocities of the flame, shock wave, flow behind the shock wave, $V_{C\text{-}J}$ and sound velocity of combustion products (b); the order of local flame arrivals at different peripheral locations in measuring cross-section (c)

Before the formation of the equilibrium detonation, the overdriven detonation wave was observed (Figure 3b). The overdriven degree for tested mixtures was about 2.5. In our experiments at the end of test section the velocities of detonation wave measured by pressure sensors and ion sensors exceeded by about

20 % of C-J velocity. At further detonation wave propagation along the tube, the measured and calculated values of the velocity became closer.

Two typical stages of flame acceleration were observed in experiments for both mixture compositions. At the flame velocities near or more than the velocity of the chocked flow behind the leading shock wave (V_{flow}), but less than isobaric velocity of sound of combustion products (V_{sound}), the spatial flame structure was highly unstable and there were strong transverse vibrations (Figure 2c). For the case shown in Figure 2c the transverse components of the flame velocity were about 400 m/s. It was close to the velocity of the chocked flow behind the leading shock wave. Thus the transverse flow velocity was close to the velocity of sound behind the leading shock wave, and the accelerating flame vibrated in the direction perpendicular to the axis of the tube. In these regimes the leading and remote edges of the flame were changing their axial location continuously. In some measuring cross-sections the rotation of the flame front along the tube as a single complex was observed.

When the flame velocities have achieved the isobaric sound speed of combustion products the spatial flame structure became stable (Figure 3c). In these cases, the leading and remote edges of the flame propagated along the tube as almost the stable complex with a certain (different for different experiments) orientation. At the same time the spatial shape of flame between the leading and remote edges were less stable and demonstrated minor transverse vibrations.

4 Conclusions

The experimental study of DDT in the stoichiometric acetylene-oxygen mixture with70 % of argon dilution and with 60 % of nitrogen dilution at initial pressure 20 – 35kPa and 19 – 50 kPa respectively in the smooth-walled round tube was carried out. X-t diagrams of the process were obtained. The spatial shape of the flame during acceleration was studied, and the velocities of the flame and shock wave at DDT were found.

The flame extension reached the maximal value to 0.073 and 0.172 m for the mixture with Ar and N_2 respectively. The maximal registered distance between the leading shock and the flame front was 0.413 and 0.347 m for mixture with Ar and N_2 dilution respectively. This parameter decreased dramatically before the onset of DDT and attained the minimal values of 0.068 and 0.048 m for mixture with Ar and N_2 respectively.

Two typical stages of flame acceleration were observed in experiments for both mixture compositions. At the flame velocities near or more than the velocity of the chocked flow behind the shock wave, but less than isobaric velocity of sound of combustion products, the spatial shape of the flame was highly unstable and there were strong transverse vibrations. The transverse component of the velocity of flame front was close to the velocity of the chocked flow behind the leading shock wave. At the flame velocities near the isobaric sound velocity of combustion products the structure of the flame front became stable.

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