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On Spontaneous Transition to Detonation at Low Combustion Pressures in Pure Acetylene

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Many investigations have been devoted to the question of the spontaneous propagation of flame in pure acetylene. On the basis of these investigations, until recently it was accepted that in acetylene at initial pressures below 1.35–1.40 ata spontaneous propagation of the reaction zone (flame) is impossible.

In work ([1]) it was shown that the limit of flame propagation at pressures of 1.35–1.40 ata is connected with the power of the ignition source used, and not with the fact that, at the indicated initial pressures, spontaneous propagation of the flame is impossible because of extraordinarily large losses of energy from the flame reaction zone into the surrounding space. It was also shown there that the true pressure limit of flame propagation is equal to 0.65 ata. Sufficient attention has also been given to the study of the propagation of a detonation wave in pure acetylene. However, at an initial acetylene pressure below 1.4 ata, in these investigations detonation was initiated by the explosion of charges of condensed explosives or by shock waves formed when the membrane of a chamber was ruptured, where acetylene exploded at a high initial pressure. Worthy of attention is work ([2]), in which the authors initiated detonation of acetylene at initial pressures of 1.0–1.4 ata by a shock wave formed when the membrane of a chamber was ruptured by an explosion of acetylene at a pressure of 2.5–5.0 ata. In the investigated section of a tube 20 m long and 300 mm in diameter, explosions of acetylene were observed with an increase in pressure by a factor of 10–12, and combustion regimes in which the pressure increased by a factor of 100. In the latter case the authors believe that detonation occurred in the experiment, and they estimate the wave velocity at 2000 m/sec.

In work ([3]) the transition of combustion to detonation in pure acetylene was investigated in tubes 100, 200, and 360 mm in diameter and 20 m long. A transition from combustion to detonation was observed in a tube 100 mm in diameter at initial pressures of 2.4 ata and above, when decomposition was initiated by the burnout of wires; at pressures of 1.4 ata and above, when initiation was by hot reaction products from a forchamber. In a tube 360 mm in diameter, in the range of initial pressures 1.6–2.2 ata, no transition of combustion to detonation was observed when decomposition was initiated by the burnout of a wire; instead, combustion regimes were observed in which, at the end opposite to igni-

Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

tion, maximum pressure values were recorded that exceeded the initial pressure by a factor of 330–656. At an initial pressure of 1.05 ata, when decomposition of acetylene was initiated by an electric spark, by discharging a capacitor through the spark gap, flame propagation was observed with an average velocity of 36 m/sec.

An experimental study of the possibility of transition of combustion to detonation in pure acetylene in the range of initial pressures 1.0–1.4 ata is, in addition to being of scientific interest, of great practical importance for developing scientifically grounded recommendations on safety procedures when working with acetylene.

The experiments were carried out in two variants: in a steel tube 360 mm in diameter and 100 m long; and in the same tube, but with a flame arrester attached at one end, beyond which there was another section of tube 24 m long and 200 mm in diameter. The motion of the reaction zone in pure acetylene was recorded by means of thermocouples arranged along the entire length of the tube at intervals of 8 m, the heating of which was recorded on the film of loop oscillographs. The film also recorded the change in pressure in the acetylene during combustion by means of DD-10 transducers located at the end of the tube opposite the ignition end. The initiation of acetylene decomposition was carried out at one end of the tube by discharging a high-voltage capacitor through a spark gap. The discharge energy was ~ 200 joules and only slightly exceeded the minimum ignition energy at an initial pressure of 1 ata. The tube was preliminarily evacuated to a pressure of ~ 10 mm Hg and filled with acetylene from a battery of cylinders to a pressure exceeding the initial pressure in the experiment. The acetylene was passed through an absorber with activated carbon to remove traces of acetone.

Fig. 1. Diagram of the apparatus for investigating modes of propagation of the chemical-reaction zone (flame) in pure acetylene. **I** –ignition system. **II** – evacuation and filling system, **III** –system for recording flame propagation, **IV** –pressure-measurement system

Fig. 2. Photographic recording of thermocouple-heating traces and of the pressure change ahead of the moving reaction zone (the pressure transducer was located inside the flame arrester) for the experimental conditions $P_0 = 1.0$ ata, $t = 25^\circ$. The pulsation frequency of the time marker is 100 Hz

Excess acetylene was vented to the atmosphere at the end of the tube opposite

Fig. 3

Figure 3: Fig. 3

the filling end. Before the experiment was conducted, a sample was taken from the tube for analysis. The percentage of acetylene in the samples taken was 98-99. A diagram of one of the experimental variants is shown in **Fig. 1**.

In Fig. 2, for the experimental conditions $P_{\text{initial}} = 1.0$ ata and an acetylene temperature of 25°, there is shown a specimen record of the heating of thermocouples by a flame propagating through acetylene and by a detonation wave on the photofilm of a loop oscillograph, as well as a record of the change of pressure in the tube ahead of the moving reaction zone. From examination of the photographic record it is evident that, before the transition of combustion to detonation, a considerable acceleration of the flame takes place. In the 20-28 m section the average flame velocity was $\sim$ 700 m/sec; in the 28-36 m section it was already $\sim$ 1300 m/sec. Steady detonation was recorded in the 36-44 m section and beyond. From the record of the pressure change by a sensitive transducer (1 kg/cm^2 corresponds to 3 mm on the photographic record) during combustion, it is seen that up to the moment of transition of combustion to detonation, the pressure ahead of the flame front practically does not increase. A pressure rise is recorded only from the moment the detonation wave arrives at the location of the pressure transducer. Thus, in this experiment the transition of combustion to detonation occurred according to the classical scheme.

Fig. 3. Photographic record of the heating of thermocouples for the experimental conditions
$P_0 = 1.1$ ata, $t = 25°$. The pulse frequency of the time marker is 100 Hz.

Table 1

P_{initial}, ata	Acetylene temperature, °C	Location of transition to detonation from the ignition point, m	Time from ignition to transition to detonation, sec	Note
1.57	25	36-44	1.36	Detonation-wave velocity $\sim$ 2000 m/sec
1.38	40	36-44	1.82	Detonation-wave velocity $\sim$ 2000 m/sec

P_{initial}, ata	Acetylene temperature, °C	Location of transition to detonation from the ignition point, m	Time from ignition to transition to detonation, sec	Note
1.1	25	36-44	1.62	Detonation-wave velocity $\sim$ 2000 m/sec
1.09	–	36-44	1.71	Detonation-wave velocity $\sim$ 2000 m/sec
1.0	25	36-44	1.36	Detonation-wave velocity $\sim$ 2000 m/sec
0.89	40	–	–	Transition of combustion to detonation was not observed.

In Fig. 3 there is shown a photographic record of the heating of thermocouples for an experiment at an initial pressure of 1.1 ata and an acetylene temperature of 25°. In this case, in the 20-28 m section the average flame velocity was only 300 m/sec. However, the transition of combustion to detonation also occurred in the 36-44 m section, and in the subsequent section of the tube steady detonation was recorded. Table 1 gives the results of experiments, po

obtained when the initial acetylene pressure was varied in the range from 0.89 to 1.57 ata.

It should be noted that the ignition energy of acetylene at an initial pressure $P_{\text{init}} = 1.0$ ata is 5-6 orders of magnitude greater than the ignition energy of fuel-oxygen mixtures. Consequently, the width of the reaction zone in an acetylene flame is also several orders of magnitude greater. However, despite such a substantial difference in physicochemical properties, the transition of combustion to detonation in pure acetylene with a weak initiation source occurs just as readily as in fuel-oxygen mixtures. The transition of combustion to

detonation in pure acetylene is completed over a length approximately equal to 100 tube diameters.

The ease of transition from combustion to detonation in pure acetylene is apparently explained by the developed surface of the flame front and by the high expansion rate (at the combustion temperature) of one of the components of the decomposition products, i.e., hydrogen.

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Note: Figure translations are in progress. See original paper for figures.