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Abstract

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THE MECHANISM OF PREDETONATION FLAME PROPAGATION IN ROUGH TUBES

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Numerous works have been devoted to the question of the onset of detonation in rough tubes ([1–5]). These works clarify questions concerning the causes of flame acceleration, the specific mechanism of acceleration, and the influence of various factors—the degree of roughness, the composition of the mixture, and the initial pressure—on the onset of detonation.

The purpose of the present work is to study the mechanism of combustion and to elucidate the structure of accelerating flames in the predetonation period under the conditions of rough tubes, in which the mechanism of detonation propagation with adiabatic ignition of the gas by compression in the detonation wave is realized.

In our experiments a semi-closed tube 900 mm long was used, with a hydraulic resistance $\lambda = 0.08$. Roughness was produced by gluing brass shavings, with an average size of $2 \times 1.5 \times 0.5$ mm, onto two opposite sides of a square channel 20×20 mm. The other two sides of the channel were smooth surfaces of optical glass, through which halftone frame-by-frame photography was carried out on moving film, in the form of a relative section of the propagating flames and shock waves. The combustible mixture (H_2+ normal air and air enriched with oxygen up to 28.7%), as well as its ignition by a weak electric spark, was supplied at the closed end of the tube.

As a result of the experiments, a picture was obtained of the development of combustion in the predetonation period, and the possibility was established of distinguishing three successive stages in this process.

The first stage is the short-time propagation of a laminar flame after ignition of the mixture. In the second stage, combustion takes place in a turbulent flow; the flame front is strongly curved and somewhat drawn forward. The sources of ignition of the mixture in this case are the flame kernels protruding farthest forward. In these stages the flames are analogous to flames in smooth tubes; photographs of the latter may be found in many works, for example ([6,7]). Upon reaching a shock wave (Fig. 1, see insert to p. 584) of definite intensity, formed ahead of the accelerating turbulent flame, the third stage of predetonation combustion begins. In this stage combustion is effected in the

Figure 1

Figure 1: Figure 1

Figure 1

Figure 2: Figure 1

form of a complex of a shock wave with a turbulent flame. Ignition of the mixture already occurs at the rough walls, near the wave front. From the walls the flame propagates toward the center of the tube, forming a cone-shaped leading surface, behind which there is a turbulent combustion zone in the form of a burning cord*.

Figure 2 (see insert to p. 584) presents 9 frames of the propagation of combustion during the transition from the second stage to the third. In the first 4 frames

* An analogous mechanism of combustion was considered for the case of detonation in rough tubes by Ya. B. Zel' dovich ([8]) and for smooth tubes by M. A. Rivin ([9]).

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Fig. 1. Debyegrams: **a** –initial β-leishite; **b** –β-spodumene (standard); **c** –synthetic β-spodumene

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Fig. 1. Shock wave ahead of the front of a turbulent flame in a rough tube

Fig. 2. Formation of a combustion mechanism with ignition at the tube walls in a mixture of 25% H_2 + 21.5% O_2 + 53.5% N_2

on the left one can see the propagation of a turbulent flame with a somewhat hemispherical surface immediately behind the shock wave. The fifth and subsequent frames record combustion in the third stage in the form of a complex with ignition at the rough walls.

The further development of the complex is characterized by an increase in its velocity and by an increase in the length of the burning plume, which in some cases reaches 5 or more tube diameters.

Combustion of the compressed gas takes place under conditions of a turbulent boundary layer and a system of waves reflected from the roughness. Under these conditions

Figure 2

Figure 3: Figure 2

Table 1

Mixture	Mixture	Mixture	D, $\frac{m}{sec}$	Mixture	Mixture	Mixture	D, $\frac{m}{sec}$
H_2, %	O_2, %	N_2, %		H_2, %	O_2, %	N_2, %	
21.75	22.45	55.8	890	40	17.2	42.8	1065
22.7	22.2	55.1	925	44.25	16	39.75	1066
24.25	21.73	54.02	930	45.85	15.53	38.62	1090
25	21.5	53.5	935	50.6	14.18	35.22	1152
30.8	19.88	49.32	990	54.15	13.15	32.7	1380

the long plume of the complex is unstable and undergoes a strong rotational and oscillatory motion, which, when the complex exists for a long time, leads to the breakup of the plume into parts and to a shortening of the length of the complex to 1.5–2 tube diameters. The acceleration and development of the complex ends with the onset of detonation at the front of the shock wave. The mixture enclosed in the complex gradually burns out behind its front.

The velocities of the shock wave at which a complex forms in mixtures of various compositions were measured. The measurement data are given in Table 1.

The formation of the complex occurs in a time not exceeding 30–50 μsec. During this time the flame is located at a distance of 0.5–3 tube diameters from the wave front. However, the direct diffusional and thermal influence of the flame on ignition of the mixture apparently does not play an essential role. The latter is confirmed by experiments in which, upon transition of an artificial shock wave of the corresponding intensity from a smooth tube into a rough one, a complex is formed analogous to the complex in the predetonation period.

In conclusion it is necessary to note that the mechanism considered for the predetonation propagation of flame is typical for tubes over a wide range of roughness, although in each case there are its own particular features.

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