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TITLE: An Experimental Study of the Role of the Nonstationary Character and Non-One-dimensionality of the Zone of Component Transformation in the Combustion Process in Condensed Mixtures

[Eksperimental'noye issledovaniye roli nestatsionarnosti i neodnomernosti zony prevrashcheniya komponentov v protsesse goreniya kondensirovannykh smesey]

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A great many experimental studies made in recent years have been devoted to investigation of the mechanism of combustion of condensed mixtures [1-11]. Theoretical concepts on the combustion of mixed condensed systems were developed in [12-15]. Nevertheless, there is still no unanimous point of view concerning the mechanism of condensed mixtures and the physical nature of a number of laws governing the combustion of these systems to a considerable extent remains unclear.

The objective of this study is clarification of the role of one factor characteristic of the process of combustion of condensed mixtures and usually absent (or unimportant) in the process of combustion of individual explosives and nitroglycerine powder. This distinguishing characteristic is the nonstationary character and non-one-dimensionality of the combustion zone. In particular, the non-one-dimensionality of the combustion zone is graphically demonstrated in an investigation made in [6] of the structure of the burning surface of condensed mixtures. Over this surface there are sectors consisting either of an oxidizer or a fuel; in addition, the surface is essentially nonplane because the mean surface level of the oxidizer differs from the mean surface level of the fuel. Since the oxidizer grains have an irregular configuration, have a definite spatial distribution and distribution by grain size, the configuration of the burning surface at each time has a random, stochastic character.

Despite the fact that with adequate pulverization of the mixture components the combustion occurs with a certain mean rate, the processes in the combustion zone will be nonstationary. This nonstationary character can be caused, in particular, by the fact that the regions of the oxidizer and fuel continually change in size, configuration and relative position. If one observes some point on a burning

surface having fixed coordinates as the mixture burns first the oxidizer and then the fuel will be present at this point. This temporal alternation of the fuel components at a fixed point on the burning surface causes the diffusion and heat conduction processes to be nonstationary in the combustion zone and makes it necessary to examine ignition processes in the newly forming sectors of the surface.

This nonstationary character of the combustion zone, associated with temporal alternation of sectors of fuel and oxidizer at a given point on the burning surface, can be eliminated by combustion of a mixture composed of parallel layers of fuel and oxidizer in such a way that the combustion front propagates along these layers (Fig. 1a). The possibility of propagation of combustion along the oxidizer - fuel discontinuity was demonstrated in studies by N. N. Bakhman [1, 4]. A detailed theoretical investigation of fuel combustion in the case of a stratified ("sandwich") structure of the condensed phase was made in a study by Nakhbar [12]. The literature makes no reference to experimental checking of this theory.

In the experiments described below the fuel used was plexiglass and the oxidizer was pulverized potassium perchlorate with particles having a mean diameter  $\sim 6 \mu$ . Ordered samples (Fig. 1a) were used in making two series of experiments (Fig. 2, 1 and 2) with the plexiglass barriers separating the layers of oxidizer 0.5 and 0.35 mm thick respectively. An equivalent disordered mixture (Fig. 1b) had the same relation of components as the ordered mixture and the mean diameter of the plexiglass particles was 0.4 mm. The density of compaction of the mixture was selected in such a way that the local density of  $KClO_4$  in the ordered and disordered systems was identical ( $\sim 1.6 \text{ g/cm}^3$ ).

The samples were prepared by cutting slits in rectangular blocks of plexiglass. Then the slits were manually

packed with oxidizers. A uniform density of the oxidizer in the slit was achieved by a careful packing and the uniformity of combustion of the layers was checked. The combustion of the samples was in a constant pressure capsule in a nitrogen atmosphere and was photographed by a "Konvas" movie camera. The ordered samples could not be ignited at atmospheric pressure and the disordered samples with extremely strong ignition burned unstably, usually with rapid attenuation.

At a pressure greater than five atmospheres both the ordered and disordered mixtures burned stably. Figure 3 illustrates the characteristic appearance of the combustion front of an ordered system at a pressure of 20 atmospheres. The combustion front breaks down into individual flares. At a pressure greater than 40 atmospheres, the plexiglass barriers 0.5 mm thick cannot be ignited but with a thickness 0.35 mm their combustion is complete even at 60 atmospheres. When  $p = 60$  atmospheres, (Fig. 2, 1) the fuel sometimes broke through along the oxidizer - fuel discontinuity and there then was a surge of oxidizer from the slit.

One of the principal corollaries of the Nakhbar theory [12] is the conclusion that the combustion rate for an ordered system is not dependent on pressure. Curves 1 and 2 on the graph indicate that at least for this oxidizer, fuel pair this theoretical conclusion sharply contradicts experimental data. The curve 3 represents the dependence of combustion rate on pressure for a disordered mixture equivalent in its chemical composition and density to the ordered mixture. At a pressure of five atmospheres, the disordered system burns almost twice as slow as the ordered mixture, but with a pressure increase the combustion of the disordered system transpires far more rapidly than in the ordered system. In particular, already at 40 atmospheres, the combustion rate for the disordered mixture could not

be determined.

Thus, at pressures of several tens of atmospheres the processes associated with the nonstationary and disordered character of the combustion zone are extremely important and must be taken into account in the theory of combustion of condensed mixtures. Now we will briefly discuss those factors which can give rise to a difference in the combustion rates for ordered and disordered systems. Among these factors the most important apparently are the following: 1) in a disordered mixture there is a strongly developed surface of contact between the fuel and oxidizer in the layer of the condensed phase adjacent to the fuel surface. This should lead to an increase in heat release in the reaction layer of the condensed phase of the disordered system and a corresponding increase in its combustion rate; 2) the nonstationary character of the processes of heat and mass transfer in the gas phase near the burning surface, associated primarily with the formation of new sectors of fuel and oxidizer on the burning surface, apparently should reduce the combustion rate; 3) a higher degree of premixing of the products of gasification of fuel and oxidizer entering into the gas phase can lead to a small increase in the combustion rate in the case of a disordered mixture; 4) the conditions for dispersion of the matter of the k-phase for ordered (if this phenomenon occurs in general only for it) and disordered systems are substantially different. The role of this factor in increasing or decreasing the combustion rate is difficult to predict a priori.

The results of the experiments described above can be interpreted in the following way. According to modern concepts on the mechanism of combustion of condensed systems (such as [11]) the quantity of heat released in the condensed phase increases with an increase in pressure. Therefore, in a disordered system at increased pressures, the first

of the above-mentioned factors enters into operation and the combustion rate exceeds the combustion rate for an ordered system.

The problem of the influence of the degree which the structure of a fuel - oxidizer system is ordered is of great importance for formulating a mathematical model of the combustion of mixed systems. In a study by N. N. Bakhman [3] devoted to investigation of the combustion of so-called bidisperse systems, it was demonstrated that the combustion rate of a mixture is not dependent on the mean diameter of the oxidizer particles but on the form of the particle-size distribution function for the oxidizer grains.

The results of this study also definitely indicates a dependence of the combustion rate on the degree to which the structure of the fuel-oxidizer system is ordered.

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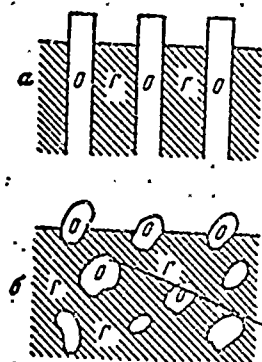


Figure 1, a and b      O = oxidizer; F = fuel;

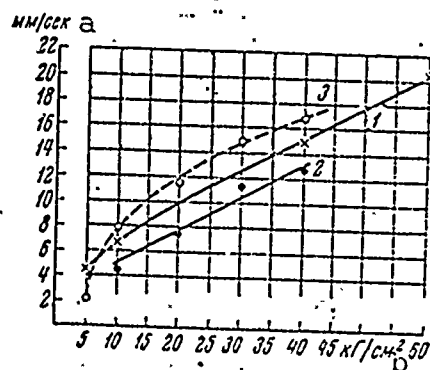


Figure 2. Key: a- mm/sec.; b- kg/cm²;



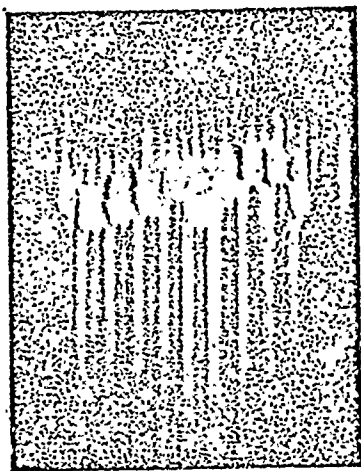


Figure 3.