PHYSICAL CHEMISTRY

V. E. GORDEEV, V. F. KOMOV, Ya. K. TROSHIN

1965

SovietRxiv

Abstract

Full Text

PHYSICAL CHEMISTRY

V. E. GORDEEV, V. F. KOMOV, Ya. K. TROSHIN

ON DETONATION BURNING OF HETEROGENEOUS SYSTEMS

(Presented by Academician V. N. Kondrat' ev on 24 VII 1964)

At present, both the conditions of propagation and the mechanism of detonation burning of homogeneous gaseous mixtures have been studied in considerable detail ([1]), but detonation combustion of heterogeneous systems still remains a little-studied area among nonclassical types of detonation burning. This area includes explosions occurring in pipeline mains and gas ducts filled with air or oxygen and coated with a layer of combustible material, for example coal dust or oil.

In works ([2],[3]) the possibility was demonstrated of the propagation of detonation burning in tubes coated on the inside with a thin layer of lubricating oil and filled with oxygen or air; it was established ([3]) that in such heterogeneous systems there may exist rapid accelerating combustion with a subsequent transition to detonation. The present work describes the results of a study of the limits for the onset and propagation of detonation burning in heterogeneous systems. The study of detonation burning of thin layers of petroleum oils applied to the walls of a tube filled with gaseous oxygen at atmospheric pressure was carried out by recording the process in time on photographic film by means of a ZhFR-2 mirror high-speed camera.

In most experiments a steel tube 1.6 m long with an internal diameter of 22 mm (the main tube) was used; along its generatrix two slots 700 mm long and 2 mm wide were cut. Before an experiment the slots were covered with glass windows. Detonation was initiated either by the explosion of an aluminum wire 25 mm long and 0.7 mm thick from the discharge of a 100 μF capacitor charged to 2.4 kV, or by detonating a charge of lead azide of up to 0.7 g, or else by a shock wave formed when gas detonation was transferred from a tube filled with a homogeneous stoichiometric methane–oxygen mixture into the tube with the heterogeneous system.

It was established experimentally that, in contrast to homogeneous gaseous mixtures, where overdriven detonation arises in the immediate vicinity of a strong initiation source, in heterogeneous systems, with all the strong initiation sources mentioned above, accelerating combustion arises and passes into detonation if the layer of lubricating oil is greater than a certain limiting value. If, however,

Fig. 1

Figure 1: Fig. 1

the layer of lubricating oil is smaller than this value, even a strong initiation source can produce only decaying combustion (near it).

Under the conditions of our experiments, accelerating combustion with a velocity from ~ 200 m/sec was observed in the initial section of the tube and reached ~ 800 m/sec in the section of the tube located up to ~ 600 mm from the point of initiation.

In the first series of experiments the minimum value was determined of the amount of lubricating oil per unit surface area of the tube (δ_1, $\mathrm{g/m^2}$) at which the onset of accelerating combustion, passing into detonation in the heterogeneous system, is possible: lubricating-oil film—gaseous oxygen. The results of the experiments are given in Table 1. From its data it is seen that for oils (industrial-12 and VM-4) accelerating

combustion in heterogeneous systems arises and passes into detonation at $\delta > \delta_1 \simeq 28$ $\mathrm{g/m^2}$, which corresponds to a thickness of the oil layer on the tube wall equal to $\lambda_1 \simeq 32$ μ. If, however, the value of the surface concentration of oil on the tube walls is less than the limiting value ($\delta < \delta_1 \simeq 28$ $\mathrm{g/m^2}$), then decaying combustion occurs. Figure 1A shows a photograph from this series of experiments. It shows the process of propagation

Fig. 1. Photographic recording of the process of propagation of detonation combustion. **A**—in a heterogeneous system oxygen—VM-4 oil, surface concentration of oil 33 $\mathrm{g/m^2}$, detonation velocity ~ 1400 m/sec in a tube of diameter 22 mm. **B**—in a heterogeneous system oxygen—industrial oil 12, surface concentration of oil 2.5 $\mathrm{g/m^2}$, detonation velocity ~ 1700 m/sec in a tube of diameter 22 mm

of detonation combustion in the heterogeneous system oxygen—VM-4 oil, surface concentration of oil $\delta \simeq 33$ $\mathrm{g/m^2}$, detonation velocity $D \simeq 1400$ m/sec. Table 1 does not give the values of δ_1 for the experiments of the first series with P-28 oil (Bright Stock), because, unlike the other oils, as well as vaseline, solidol, and carbon black (soot), this oil proved to be the most stable. Thus, out of ten experiments, in seven detonation combustion did not arise even at $\delta = 400$ $\mathrm{g/m^2}$, while in three experiments an unstable—not sharply decaying—combustion process was recorded near the initiation source. Thus, in the heterogeneous system with Bright Stock oil we were unable, at the most varied values of δ, to initiate accelerating combustion and its transition to detonation either by the powerful initiation sources indicated above, or even by a No. 8M detonator cap. However, if an already preformed detonation wave, propagating in a heterogeneous system with industrial-12 and VM-4 oil, is passed into the heterogeneous system with Bright Stock oil, then detonation combustion in such a heterogeneous system in the tube can propagate steadily. In this way it proved possible to initiate steady detonation combustion with Bright Stock oil even at surface concentrations of this oil (δ) considerably smaller than those that had already been found (for industrial-12 and VM-4 oils) as the limiting surface concentrations δ_1 (necessary for the occurrence of detonation combustion from a shock wave

strong initiation source (with transition of accelerating combustion to detonation). From this fact there arose the need to find another minimum (limiting) value of the amount of lubricating oil per unit surface area of the tube (δ_2, g/m^2), at which the transfer and propagation of detonation combustion in the heterogeneous system is possible from a previously formed detonation wave in an analogous heterogeneous system. For this purpose a second series of experiments was carried out, in which an initial section was installed ahead of the main tube—a tube 22 mm in diameter and 100 cm long—in order that a detonation wave could be formed beforehand in the heterogeneous system and then pass into the main tube. The walls of the initial section of the tube were coated with VM-4 oil or Industrial 12 oil at a surface concentration approximately three times higher than the critical value ($\delta \approx 100$ g/m$^2 > \delta_1$). The walls of the section of the main tube were coated with a thin film of the oil under investigation with surface concentration (δ), lying within the limits $\delta_2 < \delta < \delta_1$.

The results of the second series of experiments for oils whose viscosity properties made it possible to apply very thin layers to the walls of the main section of the tube are given in Table 1. From the data in the table it is evident that, for all the oils investigated, detonation combustion propagated in the heterogeneous system in the main section of the tube if $\delta > \delta_2 \approx 2.5$ g/m^2, which corresponds to a thickness of the oil layer on the tube wall equal to only a few microns.

Table 1

Limiting (minimum) surface concentrations of petroleum oils on the walls of a tube in an oxygen atmosphere, necessary for the propagation of detonation combustion in heterogeneous systems in a tube 22 mm in diameter

Oil grade	I series of experiments (onset of detonation combustion—with transition of accelerating combustion to detonation—from a strong initiation source), δ_1, g/m^2	I series of experiments (onset of detonation combustion—with transition of accelerating combustion to detonation—from a strong initiation source), λ_1, μ (layer thickness)	II series of experiments (onset of detonation combustion in heterogeneous systems from a detonation wave formed in an analogous heterogeneous system), δ_2, g/m^2	II series of experiments (onset of detonation combustion in heterogeneous systems from a detonation wave formed in an analogous heterogeneous system), λ_2, μ	Calculated values for stoichiometry, δ, g/m^2	Calculated values for stoichiometry, λ, μ
Industrial-12	~ 28	~ 32	~ 1.6	~ 1.8	~ 2.2	~ 2.5
VM-4	~ 28	~ 32	~ 2.0	~ 2.2	~ 2.2	~ 2.5
P-28 (bright stock)	–	–	~ 2.3	~ 2.5	~ 2.2	~ 2.5

A typical photograph of this series of experiments is given in Fig. 1B, which shows the process of detonation combustion in the heterogeneous system oxygen —Industrial 12 oil at an oil surface concentration $\delta_2 \sim 2.5$ g/m^2 ($\lambda_2 \simeq 5$ μ), with detonation velocity $D \simeq 1700$ m/sec. Comparing this velocity with the detonation velocity recorded in the first series of experiments (Fig. 1A), we see that, for very thin layers of oil film (at small values $\delta \simeq 2.5$ g/m^2), it is somewhat higher than that in the experiments of the first series (at values $\delta \simeq 32$ g/m^2). Apparently this can be explained by the fact that, at very small surface concentrations of oil, the average composition of the combustible mixture entering the detonation-combustion zone is closer to stoichiometric. The last columns of Table 1 give the calculated values of δ and λ under the assumption that the mixture of oil vapors with oxygen burns in the detonation front in a stoichiometric ratio. In reality, in all the experiments, including those at values of δ close to the limiting values of the surface concentrations δ_2, formation of soot was observed, although the average composition of the combustible mixture entering the detonation-combustion zone corresponded rather to an excess of oxygen ($\alpha > 1$).

Because of the very small values of $\delta \gg \delta_2$, in the second series of experiments it was not possible to obtain a uniform oil layer on the walls of the main section of the tube. Visually, "dry spots" were observed in the channel of the main section of the tube; according to approximate estimates, their total area amounted to 25% of the entire surface of the tube. Since the average value of δ was calculated as the ratio of the weight of the oil to the surface area of the tube, the presence of "dry spots" caused the error in calculating the values of δ_2 to be $\pm 40\%$; for the first series, the error in calculating the value of δ_1 did not exceed $\pm 10\%$.

In order to make sure that photographs such as that shown in Fig. 1b were not the result of recording on the film the products of detonation combustion flowing from the initial section into the main section of the tube, control experiments were carried out in which the walls of this (main) tube were freed of oil. Then, each time, no glow at all was visible on the film—it remained completely clean, and the destruction was not as strong as during the propagation of detonation combustion.

As a result of the two series of experiments carried out, it was established that in the heterogeneous systems studied there exist two limiting values of the surface concentrations of oil on the tube wall: δ_1 and δ_2. By analogy with detonation in homogeneous gas mixtures, the first value δ_1 corresponds, as it were, to the explosive limit, and the second δ_2 to the detonation limit; moreover, the limiting surface concentrations for the detonation limits δ_2 are approximately 10 times smaller than those for the explosive limits.

In this sense, bright stock oil has no explosive limits, but only detonation limits for very thin oil films on the tube wall, reaching 2–3 μ.

The experimental facts described in this work will help in the future to elucidate the mechanism of detonation combustion in heterogeneous systems.

Institute of Chemical Physics
Academy of Sciences of the USSR

Received
16 VII 1964

CITED LITERATURE

1. K. I. Shchelkin, Ya. K. Troshin, *Gas Dynamics of Combustion*, Publishing House of the Academy of Sciences of the USSR, 1963.

2. R. Loison, C. R., **234**, No. 5, 512 (1952).
3. V. E. Gordeev, V. F. Komov, A. I. Serbinov, Ya. K. Troshin. *Industrial Power Engineering*, No. 12, 24 (1964).

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