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Fig. 1. Registration of compression waves during combustion in a tube of length $L = 170$ mm. Mixture: $a\text{-CH}_4 + 2\text{O}_2 + 8\text{O}_2$, $b\text{-CH}_4 + 2\text{O}_2 + 8\text{N}_2$.

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Abstract

Full Text

Physical Chemistry

S. M. Kogarko and A. S. Novikov

INVESTIGATION OF COMPRESSION WAVES DURING COMBUSTION OF GASEOUS MIXTURES

(Presented by Academician V. N. Kondrat'ev, 28 IV 1960)

When a flame propagates through an explosive gaseous mixture at a practically constant velocity, under certain experimental conditions the appearance and amplification of compression waves are observed during the combustion process^(1,2). The mechanism of the phenomenon of amplification of compression waves during combustion consists in an increase in the rate of chemical reactions in the flame zone when the flame interacts with a compression wave, and in the temporary delay, in the reaction zone, of the additionally released energy.

In the absence of external disturbances and flame acceleration, all processes occurring in the reaction zone of the flame and in the space surrounding it are stationary. There exist, on the one hand, a diffusion flux of the initial mixture into the flame reaction zone and a heat flux from the reaction zone into the initial mixture and, on the other hand, an outflow of reaction products from the flame zone.

Fig. 1. Registration of compression waves during combustion in a tube of length $L = 170$ mm. Mixture: $a\text{-CH}_4 + 2\text{O}_2 + 8\text{O}_2$, $b\text{-CH}_4 + 2\text{O}_2 + 8\text{N}_2$.

If a disturbance in the form of a compression wave is superimposed on the chemical-reaction zone, which somewhat raises the temperature and density of the reacting mixture, then the consequence of this will be an increase in the rate of chemical reactions in the flame-combustion zone. Since the establishment in the reaction zone of a new temperature corresponding to the compression of the reacting mixture by the wave occurs considerably faster than the removal, from the reaction zone into the surrounding space, of the additionally released energy, part of the excess energy is temporarily delayed in the zone. This leads to an increase in pressure in the reaction zone and to the appearance at its boundaries of additional waves, which amplify the compression waves.

The formation of the initial compression wave, as a rule, occurs from the ignition of a small volume of the mixture at the moment of its ignition by an electric spark or by another ignition source. Its formation is also possible from the accidental ignition of a small volume of the mixture already during the combustion process. Obviously, the amplitude of the initial compression wave and the degree of its amplification in the subsequent combustion process will depend on the physicochemical properties of the mixture. During combustion of a mixture in closed or semi-closed volumes, throughout the entire combustion process the compression wave, as a rule, will repeatedly encounter the flame front. Therefore it is necessary to consider repeated interactions of the compression wave with the flame reaction zone.

Since amplification of the compression wave is associated with a disturbance of the stationarity of the processes in the flame, if by the time of a repeated act of interaction of the wave

compression wave with the reaction zone, all disturbances of stationarity in the flame will be restored—all the phenomena considered earlier will be repeated. Otherwise, i.e., when a new interaction of the compression wave with the reaction zone occurs in which the restoration of stationarity of all processes has not yet been completed, the rate of release of additional energy in the reaction zone may prove sufficient only to compensate for its nonstationary dissipation into the space surrounding the flame. In this case there will be no amplification of the compression wave. In the experiment, all intermediate cases may also occur.

Table 1

Mixture composition	Tube length, mm	Maximum amplitude of the compression wave, mm
$\text{CH}_4 + 2\text{O}_2 + 10\text{O}_2$	170	19
$\text{CH}_4 + 2\text{O}_2 + 10\text{O}_2$	75	0
$\text{CH}_4 + 2\text{O}_2 + 8\text{O}_2$	170	64
$\text{CH}_4 + 2\text{O}_2 + 8\text{O}_2$	75	38
$\text{CH}_4 + 2\text{O}_2 + 6\text{O}_2$	42	0
$\text{CH}_4 + 2\text{O}_2 + 6\text{O}_2$	42	66
$\text{CH}_4 + 2\text{O}_2 + 6\text{O}_2$	32	7
9.5% $\text{CH}_4 + 90.5$ air	170	13.0
9.5% $\text{CH}_4 + 90.5$ air	75	0

For the purpose of further studying the amplification of compression waves during combustion and experimentally verifying certain conclusions of the theory, corresponding experiments were carried out.

The experiments were conducted in glass tubes 10 mm in diameter. The compression waves during combustion were recorded by means of a piezoquartz

indicator and a cathode oscilloscope on rotating photographic film. The indicator was placed at one end of the tube. The other end of the tube, where the mixture was ignited by an electric spark, was open and communicated with the atmosphere.

As a result of the investigation carried out, it was established that, during the combustion of methane–oxygen mixtures in tubes open at one end, compression waves arise and are amplified over the range of methane variation in the mixture from 7.5 to 53%. When the methane content in the mixture is decreased from 9.1 to 6.7%, at first a rapid decrease in the maximum amplitude of the compression wave is observed, and with further depletion of the mixture in methane the amplification in the combustion process of the initial compression wave ceases completely.

Fig. 2. Recording of compression waves during combustion in tubes of different lengths. Mixture $\text{CH}_4 + 2\text{O}_2 + 8\text{O}_2$: a—170 mm, b—75 mm, c—42 mm; mixture $\text{CH}_4 + 2\text{O}_2 + 6\text{O}_2$: d—42 mm.

Replacement in the mixture of excess oxygen by nitrogen in mixtures deficient in fuel leads to a sharp change in the amplification of compression waves in

during the combustion process. Since the thermal conductivity, diffusion coefficient, heat capacity, and also—in the fuel-deficient region—the maximum flame temperature remain practically unchanged in this case, a certain decrease in the value of the normal flame velocity when excess oxygen is replaced by nitrogen must therefore be due to a decrease in the rate of the chemical reaction in the flame³. In Fig. 1 are shown photographic records of compression waves in the mixtures: a) $\text{CH}_4 + 2\text{O}_2 + 8\text{O}_2$ and b) $\text{CH}_4 + 2\text{O}_2 + 8\text{N}_2$. In the second case, during combustion a very weak compression wave is recorded in comparison with the record of the compression wave during combustion of the first mixture. The results of these experiments confirm our ideas that the amplification of a compression wave depends on the magnitude of the rate of the chemical reactions in the flame zone and on its change under the action of disturbances imposed on the flame.

In order to study the influence of the frequency with which compression waves meet the flame reaction zone on the development of compression waves during the combustion process, a series of experiments was carried out with tubes of different lengths. The results of these experiments showed that, for a number of methane–oxygen mixtures and methane–air mixtures of stoichiometric composition that we investigated, there exist critical tube lengths below which the combustion process proceeds in the absence of compression waves.

Table 1 gives the experimental data, and Fig. 2, for illustration, gives the corresponding photographic records.

Analysis of the records in Fig. 2 and of the data in Table 1 leads to the conclusion that, during combustion of a mixture of composition $\text{CH}_4 + 2\text{O}_2 + 8\text{O}_2$, the maximum amplitude of the compression wave decreases as the tube is shortened,

i.e., as the frequency with which the flame meets the compression wave increases, and in a tube of length $L = 42$ mm it becomes equal to zero. In the latter case, compression waves are not detected throughout the entire combustion process. Thus, the tube length $L = 42$ mm is the critical length for this mixture. In a mixture of composition $\text{CH}_4 + 2\text{O}_2 + 6\text{O}_2$, with a larger value of the normal velocity and, consequently, a smaller width of the reaction zone, the development of the compression wave during combustion in a tube of the indicated length (Fig. 2 *c*) proceeds approximately in the same way as for the mixture $\text{CH}_4 + 2\text{O}_2 + 8\text{O}_2$ in a tube 170 mm long (Fig. 2 *a*).

The experimental data obtained for the critical tube lengths are in agreement with our theoretical ideas concerning the mechanism of amplification of compression waves during combustion. Namely, as the amount of methane in a methane-oxygen mixture containing excess oxygen is decreased, the value of the normal flame velocity decreases and, consequently, the width of the reaction zone increases. Associated with this is an increase in the time interval required for complete dissipation of the preceding disturbance. Therefore, for normal amplification, the frequency with which the compression wave meets the flame must decrease, and the critical tube length will increase.

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REFERENCES CITED

1. S. M. Kogarko, V. I. Skobelkin, *DAN*, **120**, No. 6 (1958).
2. S. M. Kogarko, *ZhTF*, **30**, 110 (1960).
3. W. Jost, *Explosions- u. Verbrennungsvorgänge in Gasen*, 1939.

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

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