Reports of the Academy of Sciences of the USSR

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1962

SovietRxiv

Abstract

Full Text

Reports of the Academy of Sciences of the USSR

1962. Vol. 146, No. 3

PHYSICAL CHEMISTRY

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EFFECT OF CURVATURE ON THE PROPAGATION VELOCITY OF A LAMINAR FLAME IN A LEAN PROPANE–AIR MIXTURE

(Presented by Academician S. A. Khristianovich, 10 V 1962)

The experimental study of a plane laminar flame encounters the difficulty of producing it, since the flames usually used in a Bunsen burner and an Edgerton–Pauling burner are not strictly one-dimensional ([1]). In addition, questions of the stability of the flame front, flame propagation in narrow tubes, combustion of gas mixtures at reduced pressures and at the limits of ignition require the study of curved flames ([2,3]). In this connection, a number of theoretical and experimental works have recently appeared devoted to consideration of cylindrical and spherical flames ([4–8]).

In the present work an experimental attempt has been made to determine the influence of the curvature of a spherical flame on its propagation velocity. Since the influence of curvature may be expected to be more significant near the limits of ignition, where the width of the combustion zone reaches its maximum value, a lean propane–air mixture was chosen. The composition of the propane was C_3H_8 92%, C_2H_6 4%, C_4H_{10} 2%.

It was observed that if a spiral turbulizer is placed near the mouth of a Bunsen burner, then at Reynolds numbers close to the critical value, in the process of large-scale oscillations behind the leading flame front, separate detached moles of fresh mixture are formed, surrounded by combustion products, which in the course of afterburning become sufficiently spherical. Since small-scale pulsations are absent at such values of Re, the combustion of these detached volumes may be regarded as laminar.

Using an optical schlieren system and frame-by-frame photography, it is possible to follow the process of their burnout with time and thus to estimate, as a function of the diameter of the sphere, the change in the flame propagation velocity, defined in this case as the propagation velocity along the normal to the flame surface.

Figure 2: Dependence of the diameter of the burning-out volume on time

Figure 1: Figure 2: Dependence of the diameter of the burning-out volume on time

In our experiments a volumetric schlieren system with frame-by-frame photography according to the Neubert scheme (^{9}) was used. The filming frequency was about 6000 frames per second. The magnification of the optical system was 0.6.

Figure 1 (see insert facing p. 588) gives a motion-picture record of one of the burning volumes obtained. Measurements of the dimensions of the volumes and of the time from the photographs were made on an IZA-2 comparator. The measurement results for four different mixtures of propane with air are shown in Fig. 2 in the form of points. Time is plotted on the abscissa axes, and the diameter of the burning volumes on the ordinate axes. The experimental points on each graph were obtained by processing several volumes; straight line 2 is given for comparison and corresponds to the combustion process of volumes with the normal velocities of a plane flame. It can be seen that, for the sizes of volumes obtained, the flame propagates with a velocity considerably greater than the normal velocity of a plane flame, especially in the last stage.

An attempt at a theoretical explanation is made under the following assumptions:

1. The propagation velocity of the flame front is directly proportional to the amount of heat supplied to a unit area of the surrounding unheated combustible mixture:

$$\frac{u_{\mathrm{p}}}{u_{\mathrm{p0}}} = \frac{r^2}{(r+\delta)^2}, \tag{1}$$

where u_{p} is the normal velocity of the curved flame, u_{p0} is the normal velocity of a plane flame, and δ is the effective width of the preheating zone.

Fig. 2. Dependence of the diameter of the burning-out volume on time: a —at $u_{\mathrm{p0}} = 15.5$ cm/sec, b —$u_{\mathrm{p0}} = 17.6$ cm/sec, v —$u_{\mathrm{p0}} = 18.2$ cm/sec, g —$u_{\mathrm{p0}} = 18.6$ cm/sec

2. The effective width of the preheating zone is inversely proportional to the normal velocity:

$$\frac{\delta}{\delta_0} = \frac{u_{\mathrm{p0}}}{u_{\mathrm{p}}}, \tag{2}$$

where δ_0 is the width of the preheating zone in the case of a plane flame. Substituting δ from (2) into (1) and solving the resulting equation, we have:

$$r = \frac{\delta_0 \left(1 + \sqrt{\frac{u_\mathrm{p}}{u_{\mathrm{p}0}}}\right)}{\frac{u_\mathrm{p}}{u_{\mathrm{p}0}} \left(\frac{u_\mathrm{p}}{u_{\mathrm{p}0}} - 1\right)}. \tag{3}$$

The result of calculation by this formula corresponds to curve 1 in Fig. 2, with the quantity δ_0 calculated from (10):

$$\delta_0 = 4.6 \frac{\bar{\lambda}}{\bar{C}_p \cdot \rho_i \cdot u_{n0}},$$

where $\bar{\lambda}$ and $\bar{C}_p$ are the mean values of the thermal conductivity coefficient and heat capacity of the mixture in the range from 20 to 1000°, and ρ_i is the density of the initial mixture. It is interesting to note that the rather primitive assumptions made in deriving formula (3) lead to satisfactory agreement with experiment. Fabri' s dependence (7) predicts a considerably weaker effect.

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Received
28 IV 1962

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

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