MEASUREMENT OF THE POLYTROPY INDEX FOR GAS-DETONATION PRODUCTS

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This method for γ is based on measurement of D_2/D_1 (ratio of velocities of incident and reflected waves) for two colliding detonation waves under conditions where one can neglect the three-dimensional structure of the reaction zone in the incident wave. The collision of these effectively one-dimensional detonation waves is described by the solution for the collision of a detonation wave with an absolutely rigid wall for the strong-wave approximation [1,2]. This approximation may give a substantial error in γ for a gas detonation, where the ratio of p_0 (initial pressure) to p_1 (pressure in detonation wave) is 0.05–0.2. We therefore deduce the relation of γ to D_2/D_1 without neglecting p_0 relative to p_1.

The conservation and other equations for the incident wave are

$$\rho_0 D_1 = \rho_1 (D_1 - u_1), \qquad p_1 - p_0 = \rho_0 D_1 u_1,$$
$$\frac{\rho_1}{\rho_0} = \frac{\gamma_1 + 1 - p_0/p_1}{\gamma_1}. \tag{1}$$

For the reflected wave (on the assumption that $\gamma_1 = \gamma_2 = \gamma$) the conservation laws give

$$\rho_2 D_2 = \rho_1 (D_2 + u_1), \qquad p_2 - p_1 = \rho_1 (D_2 + u_1) u_1,$$
$$\frac{\rho_2}{\rho_1} = \frac{p_1(\gamma - 1) + p_2(\gamma + 1)}{p_1(\gamma + 1) + p_2(\gamma - 1)}. \tag{2}$$

Here ρ and u are respectively the density and mass velocity, while subscripts 0, 1, and 2 relate to the initial mixture, the incident wave, and the reflected wave. In Eqs. (1) and (2) we make the substitutions

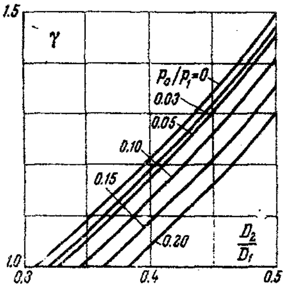

Fig. 1. Relation of γ to D_2/D_1.

$$d = \frac{D_2}{D_1} + 1, \qquad \xi = \frac{\gamma + 1}{\gamma}, \qquad \pi = \frac{p_0}{p_1} \tag{3}$$

to get

$$d\left(1 + \frac{1 - \pi}{\gamma}\right) - 1 - \frac{\xi(1 - \pi)}{4} - \left(\frac{\xi^2(1 - \pi)^2}{16} + 1\right)^{1/2} = 0. \tag{4}$$

This may be put as

$$a\gamma^2 + b\gamma + c = 0. \tag{5}$$

If the terms in π^2 are neglected, the coefficients are

$$a = 2d^2 - 5d + 1 + \pi(d - 1),$$
$$b = 4d^2 - 6d + 1 + \pi(7d - 4d^2 - 1),$$
$$c = d(2d - 1) - \pi(2d - 1)d. \tag{6}$$

Figure 1 shows solutions to Eq. (5) for γ positive and for the most probable range of D_2/D_1 (0.3–0.5) for various $\pi = p_0/p_1$; the upper curve corresponds to the solution for a strong detonation wave.

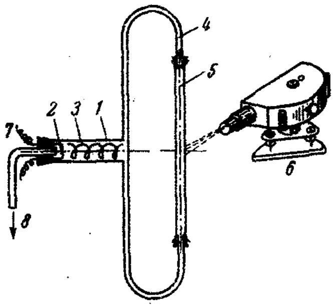

Fig. 2. The detonation tube: 1) metal tube for initiating detonation, 2) wire spiral for igniting gas mixture, 3) Shchekin spiral, 4) metal tube, 5) experimental section.

This may be used as a nomogram with the observed D_2/D_1 and p_0/p_1 to deduce γ.

Figure 2 shows the apparatus used to measure γ. The spiral 2 ignites the gas mixture in tube 1; the conversion of the combustion to a detonation is accelerated [3] by the spiral 3. Tube 1 is connected to the symmetrically placed tube 4; part 5 is made of glass and has an internal diameter of 16 mm. The middle part is viewed by a ZhFR-1 camera [4, 5].

The gas mixtures had compositions and initial pressures far from the detonation limits. The recordings were as shown in Fig. 3; D_2/D_1 is deduced from the angles α and β as follows:

$$\frac{D_2}{D_1} = \frac{\operatorname{tg} {}^1\!/_2\beta}{\operatorname{tg} {}^1\!/_2\alpha}.$$

Table 1 gives results for various mixtures, including acetylene-oxygen containing argon, for which γ = 1.67, it being assumed that the γ for this case would be larger than that for a mixture without argon. The p_0/p_1 for these mixtures were as follows: $2H_2 + O_2$ 0.05, $CH_4 + 2O_2$ 0.03, $C_2H_2 + 2.5O_2$ 0.03. For p_0 of 500 mm Hg or less, the mixtures $2H_2 + O_2$, $CH_4 + 2O_2$, and $C_2H_2 + 2.5O_2 + 2.5Ar$ showed an increase in D_2/D_1 as p_0 decreased, which evidently reflects the influence of the wave structure [6–8]. Inhomogeneity produces a complex pattern in the reflected waves near the point of reflection, the lines of propagation of the fronts being bent (Fig. 3a). There is hardly any effect on D_2/D_1 for p_0 > 500 mm Hg, and so γ was deduced from the

Table 1

D_2/D_1 for Various Initial Pressures p_0 in Gas Mixtures

p_0	D_2/D_1			
	$2H_2 + O_2$	$CH_4 + 2O_2$	$C_2H_2 + 2.5O_2$	$C_2H_2 + 2.5O_2 + 2.5Ar$
915	—	0.422±0.005	0.388±0.012	0.412±0.008
880	0.42±0.01	—	—	—
760	0.42±0.01	0.420±0.02	0.389±0.007	0.414±0.008
500	0.45±0.02	0.424±0.02	0.388±0.009	0.426±0.008

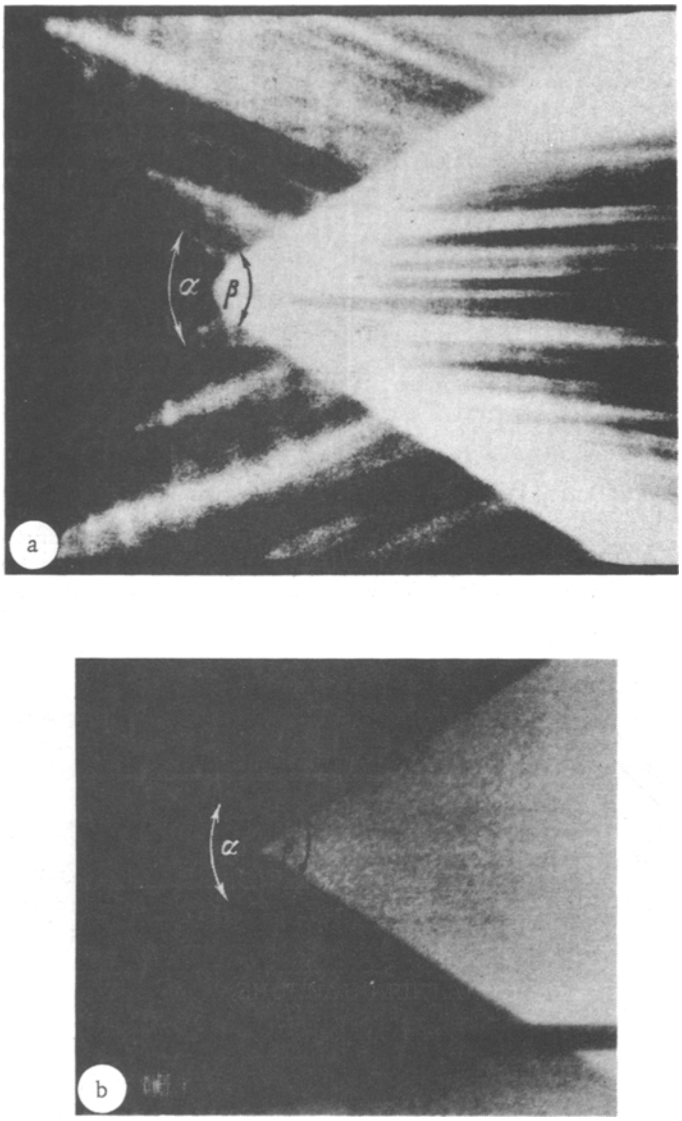

Fig. 3. Recordings of colliding detonation waves: a) $2H_2 + O_2$, p_0 = 880 mm Hg, 16 mm tube; b) $C_2H_2 + 2.5O_2$, p_0 = 300 mm Hg, 16 mm tube.

Table 2
Values of γ for Gas Mixtures

Mixture	$2H_2 + O_2$	$CH_4 + 2O_2$	$C_2H_2 + 2.5O_2$	$C_2H_2 + 2.5O_2 + 2.5Ar$
γ	1.225±0.025	1.245±0.015	1.16±0.03	1.225±0.022

data of Table 1 only for $p_0 > 500$ mm Hg, for which Fig. 1 gives the γ listed in Table 2.

It is clear that argon does increase γ for acetylene-oxygen mixtures.

REFERENCES

1. K. P. Stanyukovich, "Reflection of the front of a detonation wave", Dokl. AN SSSR, 52, no. 9, 1946.

2. Ya. B. Zel'dovich and K. P. Stanyukovich, "Reflection of a planar detonation wave," Dokl. AN SSSR, 55, no. 7, 1947.

3. K. I. Shchelkin, "Detonation in gases in roughened tubes," Zh. tekh. fiz., 17, no. 5, 613-618, 1947.

4. A. S. Dubovik and A. I. Churbakov, "The ZhFR high-speed camera," Optiko-mekhanicheskaya prom-st, no. 1, 47, 1959.

5. A. S. Dubovik, Photographic Recording of Fast Processes [in Russian], Izd-vo Nauka, 1964.

6. K. I. Shchelkin and Ya. K. Troshin, "Pulsating and spin detonations of gas mixtures in tubes, "Dokl. AN SSSR, 125, no. 1, 1959.

7. K. I. Shchelkin and Ya. K. Troshin, Combustion Gas Dynamics [in Russian], Izd-vo, AN SSSR, 1963.

8. Yu. N. Denisov, "Wall collision of gas-detonation waves with large and negligibly small ignition-induction periods," PMTF [Journal of Applied Mechanics and Technical Physics], no. 2, 96, 1966.

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