CCCXV.—*Explosions in Closed Cylinders. Part V. The Effect of Restrictions.*

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CHAPMAN and WHEELER (J., 1926, 2139; 1927, 38) have recorded the pronounced effect on the speed of propagation of flame in 10% methane–air mixtures in a tube open at both ends when a number of restricting rings are arranged within the tube. With the particular tube they used (of brass, 240 cm. long and of 5 cm. internal diameter), the maximum effect of the restricting rings (brass annuli, 1 mm. thick, 2·5 cm. internal diameter) was obtained when there were 12 of them, with a distance of 5 cm. between each. When the mixture was ignited at one end of the tube and the first of the set of rings was between 50 and 100 cm. from that end, the flame beyond the restricted region had a constant speed of 420 m. per sec., as compared with a mean speed of about 0·7 m. per sec. in an unrestricted tube. In explanation of the general effect of restrictions, it was shown that during the early stages of an explosion in a tube the unburnt mixture ahead of the flame-front is moved as a current, and the speed of the flame depends to a considerable extent on the speed of that current. The effect of one or two widely spaced restrictions is mainly on the speed of the medium in which the flame is moving, but when the restricting rings are close enough together, the tongue of flame that darts forward at the first restricting ring shoots right through the second and enflames the mixture beyond it whilst the portion between the two is still burning. The combustion of a comparatively large volume of gas is thus almost instantaneous.

During an explosion in a closed tube, the gas mixture has not so much freedom of movement as when the tube is open at both ends, but there is some movement ahead of the flame-front during the earlier stages (see Ellis, "Fuel in Science and Practice," 1928, **7**, 504). Whether that movement would be materially affected by the presence of restrictions, in such a way that a more rapid explosion would occur, has been determined in the present research.

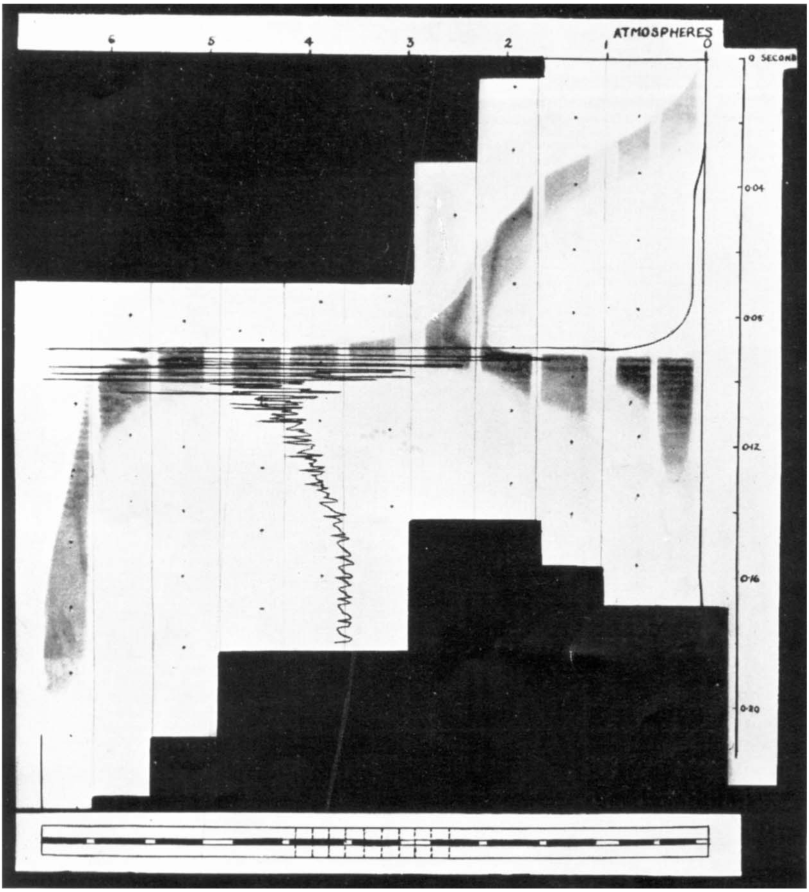
The closed cylinder used for the experiments was of gun-metal, of 10 cm. internal diameter and 171·4 cm. long. It was fitted with an ignition-plug at one end and a recording manometer of the diaphragm type at the other. A longitudinal window of quartz, 1 cm. wide, enabled the flame of the explosion to be photographed from end to end on a revolving drum. Simultaneous, carefully synchronised, records of the development of pressure and the movement of flame during the explosions were obtained. A description of the cylinder and manometer is given in this vol., p. 847.

Mixtures of Methane and Air.

Of a number of experiments made with mixtures of methane and air, one example only need be described. The cylinder was fitted with a series of ten restricting rings, equally spaced 4 cm. apart over the middle 40 cm. The restrictions were annuli of internal diameter 7·1 cm. and external diameter 10 cm. They were fitted to a brass frame of the same length as the cylinder. This frame was pushed into the cylinder, making a sliding fit, and held in position by the end plates of the cylinder, which were bolted on. The rings were of brass, 3 mm. thick, and each reduced the diameter of the cylinder at the point at which it was fitted to 7·1 cm., thereby reducing the cross-sectional area to one-half. A 10% methane–air mixture was used, initially at atmospheric temperature and pressure. The records of flame-movement (much reduced in size) and pressure-development are reproduced on Plate I, the diagram at the foot representing the cylinder. The rate of movement of the photographic paper for these records was 2·44 m. per sec.

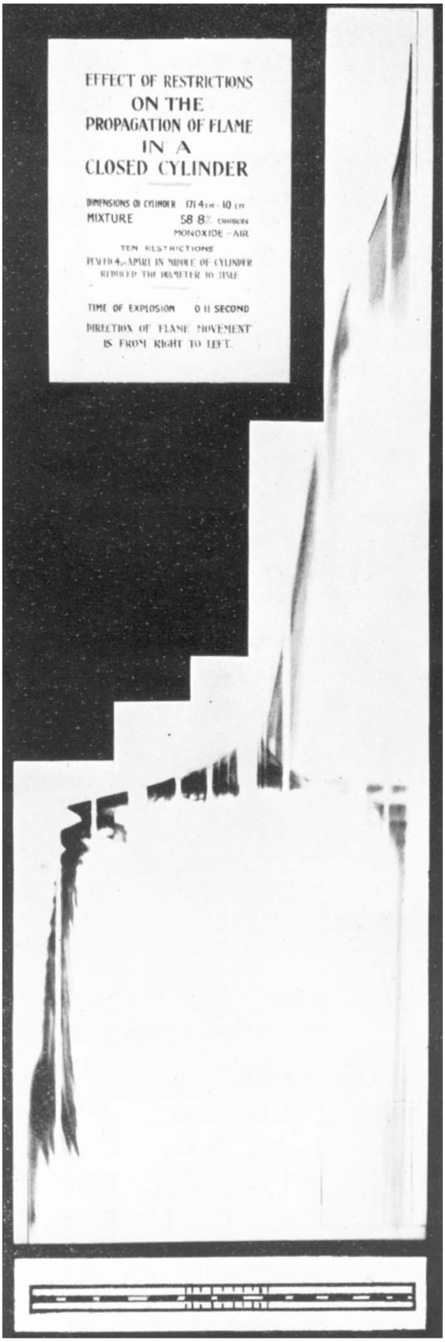
Three distinct stages of the explosion are observable, correspond-

PLATE 1.



A methane–air explosion in a restricted cylinder.

[*To face p.* 2304.]


EFFECT OF RESTRICTIONS
ON THE
PROPAGATION OF FLAME
IN A
CLOSED CYLINDER
DIMENSIONS OF CYLINDER 171 4 CM - 10 CM
MIXTURE 58 8% CARBON MONOXIDE - AIR
TEN RESTRICTIONS
TIME OF EXPLOSION 0 11 SECOND
DIRECTION OF FLAME MOVEMENT IS FROM RIGHT TO LEFT

A

Plate III.

Detail of wave-movement at A, Plate II.

ing with the progress of the flame through (1) the unrestricted portion of the cylinder over a distance of 65·7 cm. from the point of ignition at the end, (2) the restricted portion, 40 cm. long, and (3) the remaining unrestricted portion, 65·7 cm. long. From the point of ignition to the first restricting ring, the manner of movement of the flame is as in a plain cylinder of the same dimensions (*loc. cit.*, Plate II) and the mean speed is about the same, 8·5 cm. per sec. Just before the first restriction is reached, however, the flame begins to move more rapidly, and it moves very rapidly indeed through the central restricted portion of the cylinder, and over about 40 cm. beyond, attaining a speed of about 200 m. per sec. Thereafter, having travelled about 140 cm., the flame begins to vibrate, as in a plain cylinder, and travels slowly to the end.

The total time taken for the flame to travel from one end of the cylinder to the other was 0·17 sec., as compared with 0·41 sec. in an unrestricted cylinder. The maximum pressure was recorded 0·09 sec. after ignition. Since the manometer was not critically damped, the magnitude of the pressure could not be determined accurately. It was about 4·8 atms.

The acceleration of the flame (photographed along the axis of the cylinder) as it approaches the first restriction can be ascribed to an increase in the speed of movement of the unburned mixture ahead of the flame, there being a convergence of the stream lines of flow (compare Chapman and Wheeler, *loc. cit.*, p. 2145). As the flame travels rapidly forwards through the series of restrictions, a short tongue of burning gases shoots backwards and, at the moment when the last restriction has been passed, 0·09 sec. after ignition, there is an intense re-illumination throughout the cylinder between the first restriction and the point of ignition. Alternate dark and light bands appear in these re-illuminated gases, corresponding with an increase and a decrease in luminescence (the photograph being a "negative"). These bands are of the same nature as those which we have described as accompanying a vibratory methane–air explosion in the same cylinder without restrictions, but their frequency is double, 487 as compared with 240. The frequency of the bands, which remains constant, is the same as that of the undulations of the flame-front. From this it can be concluded that the vibrations are those of a longitudinal stationary wave maintained in the column of gases behind the flame-front. The frequency is probably that of the first harmonic for the system.

Mixtures of Carbon Monoxide and Air.

In explosions of mixtures of carbon monoxide and air the flames are more actinic than with methane–air explosions. In order to study vibrating flames more closely, therefore, mixtures of 58% carbon monoxide in air (saturated with water-vapour at 18°), initially at atmospheric temperature and pressure, were exploded in the restricted cylinder. The ten restrictions were in the same position as in the methane-air explosions, but their internal diameter was 5 cm. The records of flame-movement are reproduced on Plate II, the rate of movement of the photographic paper being 16·65 m. per sec., whilst Plate III shows, on a larger scale, so that the incident and the reflected waves at the end of the cylinder can be seen, the re-illumination at A, Plate II. The speed of the incident and the reflected waves is approximately the speed of sound in the hot gases.

The release of energy as the flame travelled through the restrictions was remarkably rapid, as judged by an almost instantaneous increase of pressure of about 4 atms. The sudden expansion resulting from the almost simultaneous combustion of the gas in each of the nine compartments formed by the restrictions, as a tongue of flame shot through them, produced a shock wave to which the vibrations of large amplitude can be ascribed. In the original photographs, a wave can be traced back through the burning gases, travelling at a speed of 1380 m. per sec.

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