70. Preliminary Experiments on the Modes of Propagation of Surface Combustion.1)

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Miscellaneous preliminary experiments were carried out with the purpose of studying the general modes of propagation of combustion along the plane surface of a thin layer of combustible material. For the combustible surfaces were used sheets of blotting paper or asbestos paper soaked with alcohol or some mixture of kerosene with gasoline, and also a double layer of cotton gauze stretched upon a wooden board lined with asbestos sheet. The latter was found convenient for studying the case in which the height of the flame is small in comparison with the linear dimension of the area burnt. Besides, some materials were also used which burns easily without raising flame. A brief resumé of the results obtained is as follows:

(1) With a horizontal plane surface wetted with alcohol, the flame front propagated from a central point of ignition is nearly circular and the radial velocity of propagation is nearly constant, i.e. independent of the radius of curvature of the front, provided that the latter is greater than 1 cm. The flame assumes a form like an inverted funnel on account of the centripetal air current induced by the heat of combustion.

(2) The flame front is “diffracted” at the edge of a vertical screen placed across the route of propagation. The velocity of propagation is, however, sensibly retarded on the other side of the screen after the diffraction, so that the form of the diffracted front deviates from that of a diffracted “wave,” owing probably to the effect of the inflow of air current along the screen on that very side.

(3) In the case of kerosene mixture which is characterised by a less velocity compared with that of alcohol, the flame front shows a curved polygonal form and the upper portion of the flame reveals a

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1) Most of the experiments described were carried out some years ago in the Physical Laboratory of the Imperial University of Tokyo by a number of students, except the last series which was made in the Institute by Mr. T. Utigasaki of our Laboratory. The details of the present investigation are published in Bull. Inst. Phys. Chem. Res., 9 (1930), No. 6, (in Japanese, with photograms.)
corresponding system of folds resembling to those formed at the tightened mouth of a cylindrical bag. This may be explained as due to the formation of periodic columnar vortices of air along the periphery of the flame caused by convection,\(^1\) which may be well developed on account of the slow velocity of flame front in this case.

(4) With the double layer of dry cotton gauze stretched upon a plane board such that an air space of a few mm. is left between the gauze and board, the effect was studied of the inclination of the combustible surface upon the form of flame front propagated from a centre of ignition. It was found that the down-slope velocity of propagation is generally larger than the up-slope velocity, even when the angle of inclination is only 10° say. The unsymmetry increases with the slope and at 40–50°, the up-slope velocity is practically nul. With a greater inclination, the combustible surface on the up-slope side is carbonized by the radiation of flame, but not immediately "burnt off." This unsymmetry seems to be caused mainly by the effect of the up-slope air current induced by the flame. Thus, on the down-slope side the combustion is promoted on account of the suitable supply of fresh air, while on the up-slope side the burning is hindered by the formation of eddies richly laden with CO and smoke.

(5) The effect of wind upon the flame front was studied in the cases of the surface moistened with combustible liquid as well as of the layer of cotton gauze. Provided that the wind velocity \(w\), of which the relative value is measured at a certain height above the surface, is greater than a certain value, the boundary of the area attained and burnt by the flame is determined by two straight lines meeting at the point of ignition and making an angle \(\theta\) with the direction of the wind. This angle \(\theta\) is given by

\[
\sin \theta = \frac{v}{kw},
\]

where \(v\) is the velocity of propagation normal to the front in absence of the wind, and \(k\) a constant, i.e. a kind of "drag-factor."

(6) In the author's opinion, a conflagration of large area of a town or forest may be regarded, from a \emph{macroscopic} point of view, as a case of surface combustion here in question. Thus, in connection with the present experimental investigations, the extents and forms of the areas of conflagration on the occasions of some notorious great

\(^1\) See the papers by the present author on "periodic columnar vortices" published in \emph{Rep. Aeron. Res. Inst., Tokyo Imp. Univ.}, No. 31 (1928) and 53 (1929).
fires which occurred in the ancient City of Yedo (now Tokyo), were reconstructed from a number of reliable old documents and maps. The forms of the areas burnt show some essential similarity compared with those obtained in the experimental cases. Thence, a means is afforded for estimating the relative wind velocities prevalent on the occasions of the past great fires. Maps were obtained which show the extents of the areas burnt for a number of cases. On account of the relation given in (5), a paradoxical result follows that the area burnt decreases with the increasing wind velocity, for a given distance from the source of fire. This is confirmed in the case of ancient fires.

(7) All the above experiments refer to the cases of combustion with flame. A few experiments were also made for the cases with little or no flame. Different substances in form of powder or granule were employed, being spread upon a plane board lined with asbestos. Among the materials tried, the combustible powder for "kairo" (pocket-stove) mixed with some amount of potassium nitrate was found convenient for our present purpose. This powder was spread as a thin layer and sprinkled with some ash on its surface to prevent the powder from being blown off by wind. Experimenting with this powder, it was found that, with a weak wind, the velocity of the fire front is greater on the windward side than on the lee-side owing to the better supply of \( O_2 \) on the former side. With the wind stronger than a certain limit, the reverse is the case, apparently due to the transportation of the incandescent solid particles, i.e. sparklet, by the wind towards the lee-side.

(8) The velocity of fire front, kindled at the centre of, and propagated along, a long rectangular strip of combustible surface situated at the bottom of a narrow channel between two vertical side-walls, was determined as a function of the distance of the front from the centre of ignition. The velocity decreases with the increasing distance, probably due to the effect of the air current induced by the flame. When the fire front approaches an obstructing vertical wall placed across its way, the flame begins to fluctuate at a certain critical distance from this blockade wall and then abruptly shoots forth up to the foot of the wall, or at once extinguished explosively. This characteristic phenomenon is probably connected with the formation of eddies on the flame side of the blockade, due to the inflow of the air current induced by the flame. The critical distance, \( D \), at which the anomalous propagation sets in, depends on the height, \( H \), of the
blockade wall and, moreover, the relation between $D$ and $H$ is affected sensibly by the breadth of the channel.

(9) It is remarked that the results of investigations in the line as is here suggested may be of some use for those engaged in the practice of fire prevention and extinction, especially in the case of great forest fires which are lamentably too frequent even in the present days.