Experiments on Explosive Mixtures.

A Thesis

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The object of these experiments was to study the behavior of gases when exploded in a closed vessel. The experiments, to a considerable extent, are a repetition of similar ones performed by Mr. Clerk in Scotland with an improvement in the apparatus and method of calculation.

The improvement in the apparatus was in the method of taking the cords and in the indicator used. The cords were taken upon a vertical revolving disc. The indicator used was a Labor, with an 80 figuring. The cords obtained were smooth, showing no sudden variations such as appear in those of Mr. Clerk.

The volumes were estimated by pressures read from a mercuorial manometer.

* See "The Gas Engine" by D. Clerk. Chapter VI. Page 95.
The cards as obtained on the disc were transferred to rectangular coordinates and the areas between the ordinates at the points of maximum pressure and ordinates at point two tenths of a second later were measured by a planimeter. Each area was divided by the relative quantity of gas used in that experiment. This gave a basis for comparison as to the economy of the various mixtures. The most economical mixture was found to be that with one volume of gas and two volumes of air.

The present experiments are confined to gas taken from the main supplying the city of Boston.
Apparatus — The apparatus was designed for experiments upon any gas and consisted of the following:

(a) A special device for taking the cords made to go on to any indicator in the place of the ordinary drum. (See drawing) It consisted of a 4 inch disc revolved by a pulley geared to the main shaft and ran at approximately 150 revolutions per minute.

(b) A cast iron cylinder 7" x 9" bored out similar to a gas engine cylinder and designed for 250 lbs. pressure, with a factor of safety of ten. (See drawing.)

(c) A mixer, consisting of a brass pipe, 12" long, 3/4" diameter, fitted air tight with a double piston.

(d) An air pump.

(e) A tuning fork whose vibrations
were recorded upon the disc.

The fork was fitted with a spring to hold a pencil and was vibrated by means of an electro-magnet. The vibrations were compared with those of a standard fork and it was found to vibrate at the rate of 123 single vibrations per second.

[f] A Ruhmkorff coil which gave magnitude to the spark used in exploding the mixture.

The coil and tuning fork were run by a six cell bichromate battery.

[g] A mercurial manometer consisting of a U tube graduated to tenths of an inch.

The explosion was caused by a spark introduced into the cylinder through a gutta-percha plug by means of two platinum wires.
The Experiment - The experiment was conducted as follows:

The cylinder (C), see the photographs, being free of the refuse gases from the previous experiment was rinsed by pumping out the refuse until a vacuum of 15" was obtained, as shown by the manometer; then air was admitted through the cock in the top of the cylinder. This process of rinsing was repeated six times after each experiment.

The barometer was now read and this reading was divided by say 8 (which gave a mixture of gas 1, air 7). This gave the required vacuum for this experiment. The air was pumped out of the cylinder until this required vacuum was obtained, as shown on the manometer (M), then gas was let in.
B battery,  C cylinder,  G gun pipe
K tuning fork,  J coil,  M mixer
N manometer,  P air pump.
until the pressure returned to that of the atmosphere. The mixture was then thoroughly stirred by means of the mixer (M). A card was put on the disc which was adjusted so that the pencil went out radially. The centre of the card upon the disc was found and the atmospheric line drawn.

The battery was then placed in the liquid. One was manipulated the tuning fork while the other made the electrical connections and took the card. At the word, the pencils of the tuning fork and the indicator were placed against the disc, that of the fork registering upon the same radial line with the indicator pencil; at the word, now, the electrical connections were made, that of the fork a triple before
Sample Cards.

These cards are reproduced upon the diagram on page 9.

The accuracy in the cuts shown above is impaired by inking them to preserve the lines.
that of the coil, by means of a mercury cup; hence it will be seen
the explosion began just after the fork began to register vibrations.
The fork was raised slightly thus
preventing one row of vibrations from
registering directly upon another.
The form of card obtained is
shown by the sample cards on
page 7.
The card was transferred to
one with rectangular coordinates.
See diagrams on page 9.
The abscissae are vibrations
of the tuning fork \( \frac{1}{20} \) th of an inch
is our vibration. The ordinates are
pressures, lbs. per square inch.
The scale of the spring used was 80.
Having transferred each card,
they were all cut off by ordinates
erected at 0.2 second beyond their
Abscissae $\frac{1}{25}$" equals 1 vibration.
123 vibrations in one second.
Ordinates lbs. per sq. in. 80 Spring.

One Volume gas 9 Volumes air.
One Volume gas 10 Volumes air.
One Volume gas 14 Volumes air.
One Volume gas 15 Volumes air.
points of maximum pressure and the areas between the ordinates at the points of maximum pressure and at points 2 seconds distant were measured with a planimeter.

These areas were divided by the relative volumes of gas i.e. for gas 1, air 7, the amount of gas was 1/8th of the total volume. Hence the corresponding area was multiplied by 8. Each area was treated in this manner as is shown in the column headed "areas divided by the proportion of gas". See Table of Results following page 11.

In the diagrams on page 9 and the table on page 11, there are shown the results of only one experiment for the mixtures of 1-7; 1-8; 1-9; 1-10; 1-13; 1-14; 1-15.
Table of Results

(See diagram.)

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<th>1-12</th>
<th>1-13</th>
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* Poor Cardio.
while there are shown for the mixtures of 1-11 + 1-12 results for two experiments. At least three experiments were performed for each mixture and in the cases of 1-11 and 1-12 five experiments for each.

The cards showing the best and worst results for these two last named mixtures were plotted. For 1-13; 1-14; and 1-15; the cards showing the best results were selected. In the first four mixtures the variation was not more than one pound in the maximum pressures attained; hence, the results of one experiment were deemed sufficient to show this behavior.

These cards were plotted only to 120 vibrations, which is .976 second, since beyond that point the behavior of the gas is of no consequence.
The results in the column headed "areas divided by the proportion of gas" show that the most economical mixture was gas: 1, air 10.

On either side of this for the mixtures of 1:7; 1:8; 1:9; 1:15; 1:12, the economy was nearly the same.

The ordinates at the points of maximum pressure and at 2 seconds distant were measured and the areas computed by considering that part of the cart as a trapezoid.

This was the method followed by Mr. Clerk. It was found that the inaccuracy introduced by this method was from 12½ to 6½%, as will be seen by comparison of the two columns showing the relative economy.

The table shows also the time required by each mixture to attain its maximum pressure;
likewise the pressure realized at a second beyond the point of maximum pressure. This temperature for each experiment was taken just previous to the explosion, by means of a thermometer inserted into the walls of the cylinder, but its effect for such slight variations was assumed to be inappreciable.

The probable errors in these experiments were:

1. Inability to read the manometer within .02". This would account for an error of 1% in the weaker mixtures.

2. This variation in the quality of the gas. This analysis of the gas is given on page 15. But it was impossible to have the gas tested every day although it was known to vary to a considerable
Gas Analysis.
A copy of report from Chas. W. Jenkins, Asst. Sup. of Gas and Gas Meters, Office 32 Hawley St., Boston.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Volume (%)</th>
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<tr>
<td>Illuminant</td>
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<tr>
<td>Marsh Gas</td>
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<tr>
<td>Hydrogen</td>
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<td>9.47</td>
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<tr>
<td>Nitrogen</td>
<td>3.59</td>
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<tr>
<td>Oxygen</td>
<td>1.91</td>
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</table>

(by volume)
extent in 48 hours.

In the weaker mixtures there is a possible error in the failure to mix the gas and air thoroughly. In the mixtures 1-11 and 1-12 there is a variation of from 5\% to 10\% of which the error in reading the manometer will account for but

Conclusions: In conclusion the results can be summarized as follows:

The mixture giving the highest maximum pressure was the strongest one tested; gas 1, air 7.

The mixture giving the best economy was gas 1, air 10. Although the economy for 1-7; 1-8; 1-9; 1-11 & 1-12 was not very different if we take the best cards obtained from the mixtures of 1-11 and 1-12.
In the mixture below 1-12 the economy falls rapidly.

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