THE EVEN DISTRIBUTION OF TEMPERATURE RISE WITHIN THE CATALYST TUBE IN THE OXIDATION OF CARBON MONOXIDE BY MEANS OF HOPCALITE (CuO-MnO_2)

BY

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This investigation deals with a very important part of the general problem: "The removal of carbon monoxide from 'water-gas' hydrogen by differential oxidation, with especial reference to the preparation of hydrogen for use in ammonia synthesis".

The work of Scalione, Geldard and Van Name, in collaboration with Edgar, has fairly well established the qualitative conditions under which this problem may be solved. Their work shows that by means of the principle of mixing a sufficient quantity of oxygen, or air, with the gas and passing the mixture over the catalyst known as "Hopcolite", the conditions may be so modified as to bring about the complete oxidation of the carbon monoxide without the simultaneous oxidation of the hydrogen.

Water-gas hydrogen is prepared in two standard ways, and is delivered with the following composition, according to the method of preparation: 65% H_2, 1% N_2, 32% CO_2, and 2-3% CO; or 51% H_2, 17% N_2, 29% CO_2, and 2-3% CO. It is saturated with water vapor at about 40 degrees and may contain, in addition, small amounts of H_2S, unsaturated hydrocarbons and other impurities. only the removal of CO, however, offers any great or appreciable

difficulty; the other impurities being removed by more or less standard methods.

The two best known methods for the removal of CO from the gas are the solution method, and the catalytic method. The former depends upon the conversion of CO to formates, or the absorption of CO in solution containing cuprous ions. The disadvantages of these methods lie in the fact that a very large absorption surface must be supplied; a quantity of hydrogen is lost in scrubbing, due to its solubility in the scrubbing solution; and that these solutions are constantly used up and must be replaced from time to time. The obvious advantages are: the removal of other impurities besises CO; fairly wide range of temperature and pressure control, and lack of danger of subsequent catalytic poisoning from compounds of metalloids and unsaturated hydrocarbons.

The catalytic process depends upon the oxidation or hydrogenation of CO to CO_2 or to CH_4, respectively. In processes involving the latter, three mols of H_2 are required for each mol of CO, and CH_4 gradually accumulates in the system requiring periodid attention. However, these processes remove even very small quantities of CO under a wide range of conditions, and the space-volume-life of the catalyst is quite satisfactory.

In the oxidation of CO to CO_2, at high temperatures, a relatively inactive catalyst may be used and only a small excess over the theoretical requirement of oxygen need be supplied. But the removal of CO is complete only to the point where equilibrium is reached for the temperature in question. Previous treatment with steam introduces a number of technical difficulties, such as large catalyst chambers, steam condensation, etc. The temperature control must be rigid and the gases must be purified of volatile metalloids

and unsaturated hydrocarbons.

At lower temperatures a more active catalyst must be used. Only a small excess over the theoretical requirement of oxygen is needed. The removal of CO is practically complete, and relatively high space velocities may be maintained. The temperature control must be quite rigid, necessitating rapid dissipation of the heat generated, and careful control of the CO content of the entering gas, as well as closely regulated space velocities. All gases must be carefully purified for the activity of this type of oxidation catalyst is extremely sensitive to poisoning.

In order for the above proceedure to be successful on a large scale a number of technical difficulties must be overcome. For instance, the CO removal must be so complete that less than 0.01% remains in the gas. The oxidation must be carried out in the presence of considerable amounts of moisture. It must require only a slight excess over the the theoretical requirement of oxygen, for the oxidation of CO. The oxidation of CO must be carried out in the presence of a large excess of CO_2. The space-volume-life of the catalyst must be high enough to make the consumption of catalyst fall within reasonable limits. The oxidation should be carried out at atmospheric pressure and the sensitiveness of the catalyst must not be too great. The entire process must be so simple that relatively unskilled labor can operate it.

The literature shows that a number of metallic oxides are suitable as catalysts for the preferential oxidation of CO. It shows further that there is a very distinct temperature difference between the combustion of CO and H_2. While these substances

will oxidize CO to Co_2 at a lower temperature than H_2 to H_2O, it is done at the expense of their combined oxygen. In order that these oxides act catalytically, it is necessary that they be rapidly reoxidized to their former state by the oxygen present in the gas. It is further necessary that these reactions take place rapidly in order to function at high space velocities.

The following table from Fay, Sutherland and Ferguson in Poly. Engr. 10;72 (1910), shows the action of some of the more common oxides.

Oxide	Initial Temp in Degrees C with CO	Initial Temp in Degrees C with H_2	Remarks
PbO_2	110	150	Digestion Pb_2O_3 with HNO_3
Pb_2O_3	150	170	
CoO	155	165	
Co_2O_3	less than 11	110	Oxidation of CO by Br2
NiO	120	220	
Ni_2O_3	30	65	
CuO (H_2O)	66	90	Precipitated
CuO	150	175	Oxidized Metal
Cu_2O_3	120	155	
MnO_2(H_2O)	15	145	Precipitated by oxidizing Mn .
MnO_2 Dry	87	190	
Mn_3O_4	240	255	Amorphous

This work was continued and expanded during the war by the Chemical Warfare Service with the object of developing an absorbent for CO in air to be used in gas-making. The outcome of this work was the discovery of the two component "Hopcolite" (40%CuO-60%MnO_2). This material was found most active and operated at an efficiency of 100%.

The factors influencing the mechanism of the Hopcolite oxidation depend upon the physical condition of the catalyst, which is a function of its preparation; the available oxygen content of

the catalyst; effect of temperature on the oxidation velocities of CO and H_2, and finally upon the effect of small concentrations of C_2.

Great care is taken in the preparation of the catalyst, a full account of which may be found in the work of Merrill and Scalione, Jour. Amer. Chem. Soc., 43, 1982 (1921), and need not be repeated here.

Of greatest importance are the factors influencing the distribution of temperature rise thruout the catalyst tube. There is a temperature difference of only about 25-30 degrees between the initial temperature of oxidation of CO and that of H_2, irrespective of the temperature at which the CO begins to oxidize. Consequently, if this difference should be overreached the oxidization of H_2 would immediately commence and the heat evolved would be sufficient to reduce the CuO to Cu by hydrogen, a condition easily recognized by the color of metallic copper within the catalyst mixture; causing the efficiency of the catalyst to be completely and permanently destroyed.

The factors influencing temperature distribution within the catalyst tube, according to the work of Scalione, Geldard and VanName, are as follows:

1. Removal of CO in multiple stage apparatus.
2. Control of CO concentration.
3. Effect of Space velocity.
4. Heat conductivity of the gaseous mixture.
5. Design of Apparatus.
6. Effect of mesh of catalyst.

This work further shows that the temperature rise varys directly with the percent of CO in the gas, in a given apparatus and at a constant space velocity. The temperature rise will, in

general, vary with the space velocity, depending on the particular apparatus. The design of the apparatus is therefore, quite important. With regard to the composition of the gas, it may be said that an increase in concentration of hydrogen will increase the radiating capacity of the apparatus, while the heat conductivity of the other gases, being so nearly equal, makes variation in their concentrations of little importance.

A summary of the work of the Chemical Warfare Service on this problem shows that a number of very important principles have been more or less completely established. These are as follow

1. Reproducibility of results. Under identical conditions it is shown that a given sample of Hopcolite will exhibit uniform performance.

2. Differential oxidation. It is shown that under any given set of conditions there is a temperature interval of at least 25 degrees in which practically complete oxidation of CO is practicable, and in which no appreciable oxidation of hydrogen takes place. While this is a narrow limit, making control of temperature rise quite rigid, it is nevertheless sufficient to make the differential oxidation practicable.

3. Efficiency of Hopcolite. The efficiency of this catalyst is influenced greatly by moisture and oxygen content of the entering gases. By temperature and by the space velocities.

4. Temperature control. Probably the most difficult, and certainly the most important problem is temperature control. Adequate control is thought possible thru design of a reaction chamber of high heat radiating capacity, by reduction of the concentration of CO to about 0.5%, and by distribution of the heat of reaction in some way.

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5. Life of the catalyst. Against perfectly pure gases the life of the catalyst is probably very long. It is, in general, diminished in proportion to the amounts of impurities in the gas. Indications point to sufficient effectiviness against commercial gas as to be quite practicable.

6. Influence of other gases. Carbon dioxide is apparantly without effect. Hydrogen sulphide gradually destroys the activity of the catalyst, and the effect of unsaturated hydro-carbons has not been determined.

In general it may be said that the prospect for a satisfactory solution of the problem appears to be very good. Further research should concern itself with a determination of the distribution of temperature rise in catalyst tubes of sizes applicable to large scale operation, as well as with the most effective space velocity to be employed under such conditions. With the temperature and space velocities at which complete oxidation of CO occurs at one operation. With the determination of the minimum oxygen content to be supplied and with the effect of those impurities most likely to be present in commercial gas.

Since a determination of the most effective temperatures and space velocities, with the most even distribution of temperature rise in the catalyst tube is of prime importance, our present work deals exclusively therewith.

EXPERIMENTAL.

A gas storage tank operating with an hydraulic seal, was supplied with a two-way cock, thru which a measured quantity of pure CO entered. This gas was made by treating oxalic acid with sulphuric acid. Provision was made for supplying air, which was admitted in predetermined amounts, and the whole constantly stirred for at least

half an hour by means of an electrically stirring device.

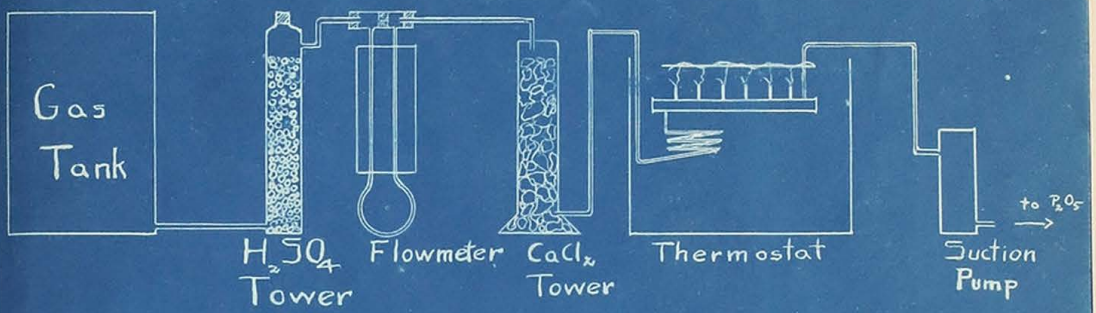
The gas was drawn thru the entire apparatus by suction, entering a sulphuric acid tower, supplied with glass beads, thence into a calibrated flow-meter from which it passed into a calcium chloride tower, thence into the catalyst tube.

The catalyst tube was fastened into the thermostat, equipped for maintaining a constant temperature within narrow limits. The gas entered the catalyst tube thru a copper coil, immersed in the bath, in order to preheat the gas to the temperature of the catalyst. Provision was made for collecting a sample of the issuing gas for analysis.

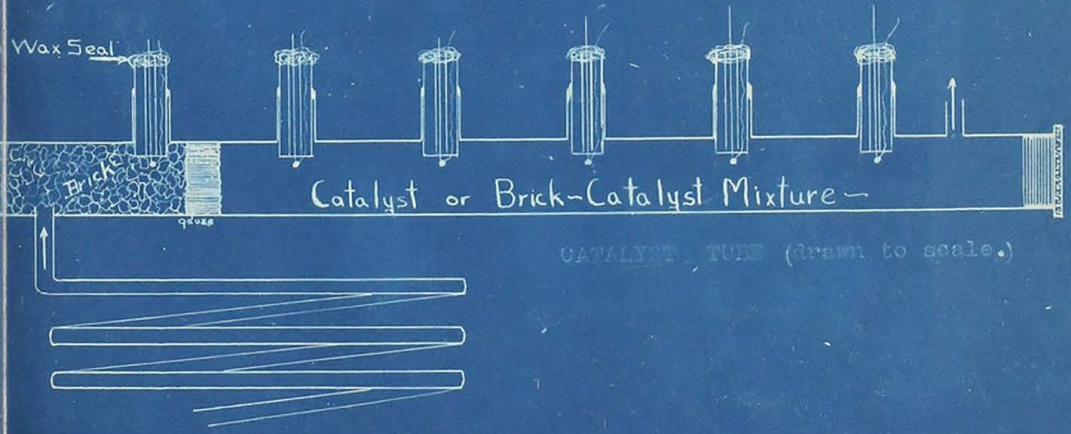
The catalyst tube is made of copper, owing to the high heat conductivity of this metal. It is supplied with six small copper tubes of about 1/16 of an inch in diameter, spaced 1 inch apart, entering the catalyst tube vertically. The catalyst tube proper is 7 ½ inches long, and ½ inch in diameter, with an effective capacity, or volume, of 17 c.c. Each of the small tubes entering the catalyst tube carries insulated wires making a contact directly beneath the entrance and about the center of the catalyst tube. Each of these thermo-couples has one wire directly connected to one galvanometer pole, and the other wire thru a mercury connection thence to the second galvanometer pole.

The galvanometer was calibrated by plotting the readings of the first thermo-couple against the other five, the first being at varying temperatures. The curve so obtained is a straight line, consequently the temperature difference between the first thermo-couple and any other one could be read off directly from the galvanometer scale.

DIAGRAM OF SET-UP OF APPARATUS USED IN THIS WORK



THERMO-COUPLE CONNECTIONS TO GALVONOMETER THRU MERCURY CONTACTS.



CATALYST TUBE (drawn to scale.)

It was found necessary in our work to make frequent determinations of the content of CO in the gas-air mixture both before and after oxidation by the catalyst, consequently the standard I_2O_5 method was adopted.

DISTRIBUTION OF TEMPERATURE RISE IN THE CATALYST TUBE

The catalyst tube was filled by placing between the standard thermo-couple, and thermo-couple #1, a copper wire gauze and pouring in the catalyst while gently tapping the tube in order to distribute the catalyst evenly. The standard thermo-couple is surrounded with an inactive substance like chipped glass in order to keep it at the temperature of the thermostat. After filling the tube a second gauze is placed between the last thermo-couple and the exit tube.

Temperature of thermostat 50 degrees. Space velocity 3600.
Content of CO in air-gas mixture 0.87%. Oxidation of CO 93%.
Arrangement of catalyst: Pure Catalyst thruout.

Thermo-couple temperature difference in degree centigrade.

No. 1.	No. 2.	No. 3	No. 4	No. 5
11.6	3.2	2.4	2.2	1.4

Temperature of thermostat 60 degrees. Other conditions same.

No. 1	No. 2	No. 3	No. 4	No. 5
13.1	3.5	2.4	2.3	0.8

These results are shown graphically on the following chart. This shows that there is a maximum temperature rise of 11.6 and 13.1 degrees at 50 and 60 degrees respectively, with only a carbon monoxide content of 0.87%, using a pure catalyst.

In order to get data upon the best temperature and space velocity to be used on a pure catalyst to get the maximum oxidation of CO, the following experiment was carried out.

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It will be seen that the effect of temperature is ... ed.

While the higher temperature gives better oxidation of CO it also gives a rather high temperature rise in oxidation, so a study of the effect of varying space velocity was undertaken.

Temperatures of thermostat 35 degrees. Space velocity 1800. Content of CO in air-gas mixture 0.98%. Oxidation of CO 90.2% arrangement of Catalyst: Pure catalyst thruout.

Thermo-couple temperature difference in degree centigrade.

No. 1	No 2	No. 3	No. 4	No. 5
8.3	3.6	1.9	1.6	0.4

Temperature of thermostat 40 degrees. Space velocity 1800 Content of CO in air-gas mixture 0.96%. Oxidation CO 96.9% Arrangement of Catalyst as above.

Thermo-couple temperature difference in degree centigrade.

No.1	No 2	No. 3	No. 4	No. 5
8.7	3.8	1.5	0.9	0.0

Temperature of thermostat 50 degrees. Space velocity 1800 Content of CO in air-gas mixture 0.96% Oxidation of CO 97.0% Arrangement of Catalyst as above.

Thermo-couple temperature difference in degree dentigrade.

No. 1	No. 2	No. 3	No. 4	No. 5
9.6	4.7	1.7	1.0	0.15

Temperature of thermostat 60 degrees. Space velocity 1800 Content of CO in air-gas mixture 0.96%. Oxidation CO 98.5% Arrangement of catalyst as above.

Thermo-couple temperature difference in degree centigrade.

No. 1	No. 2	No. 3	No. 4	No. 5
10.0	4.8	1.5	0.3	-0.1

The following chart shows these results graphically. It will be seen that the effect of temperature is quite marked. While the higher temperature gives better oxidation of CO it also gives a rather high temperature rise in oxidation, so a study of the ef-fect of varying space velocity was undertaken.

PLATE II.

Distribution of Temperature Rise.

Gas Content .96% CO.

Space Velocity 1800.

Curve 1. Temperature 35°C.
Curve 2. Temperature 40°C.
Curve 3. Temperature 50°C.
Curve 4. Temperature 60°C.

Percent Oxidation of CO.

1. 90.2 %.
2. 96.9 %.
3. 97.0 %.
4. 98.5%.

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ity, showing that the maximum temperature [illegible] maximum space velocity. It was thought best to determine the effect of varying CO content of the air-gas mixture, which follows;

Temperature of thermostat 50 degrees. Space velocity 1800
Content of CO in air-gas mixture 0.87% Oxidation CO 95.9%
Arrangement of catalyst:Pure Catalyst thruout.
Thermo-couple temperature difference in degree centigrade.

No. 1	No. 2	No. 3	No. 4	No. 5
5.8	4.4	2.6	0.2	-0.1

Temperature of thermostat as above. Space velocity 3000
Content of CO in air-gas mixture 0.87% Oxidation CO 94.2%
Arrangement of catalyst:as above.
Thermo-couple temperature difference in degree centigrade.

No. 1	No. 2	No. 3	No. 4	No. 5
9.5	7.2	5.2	2.6	1.3

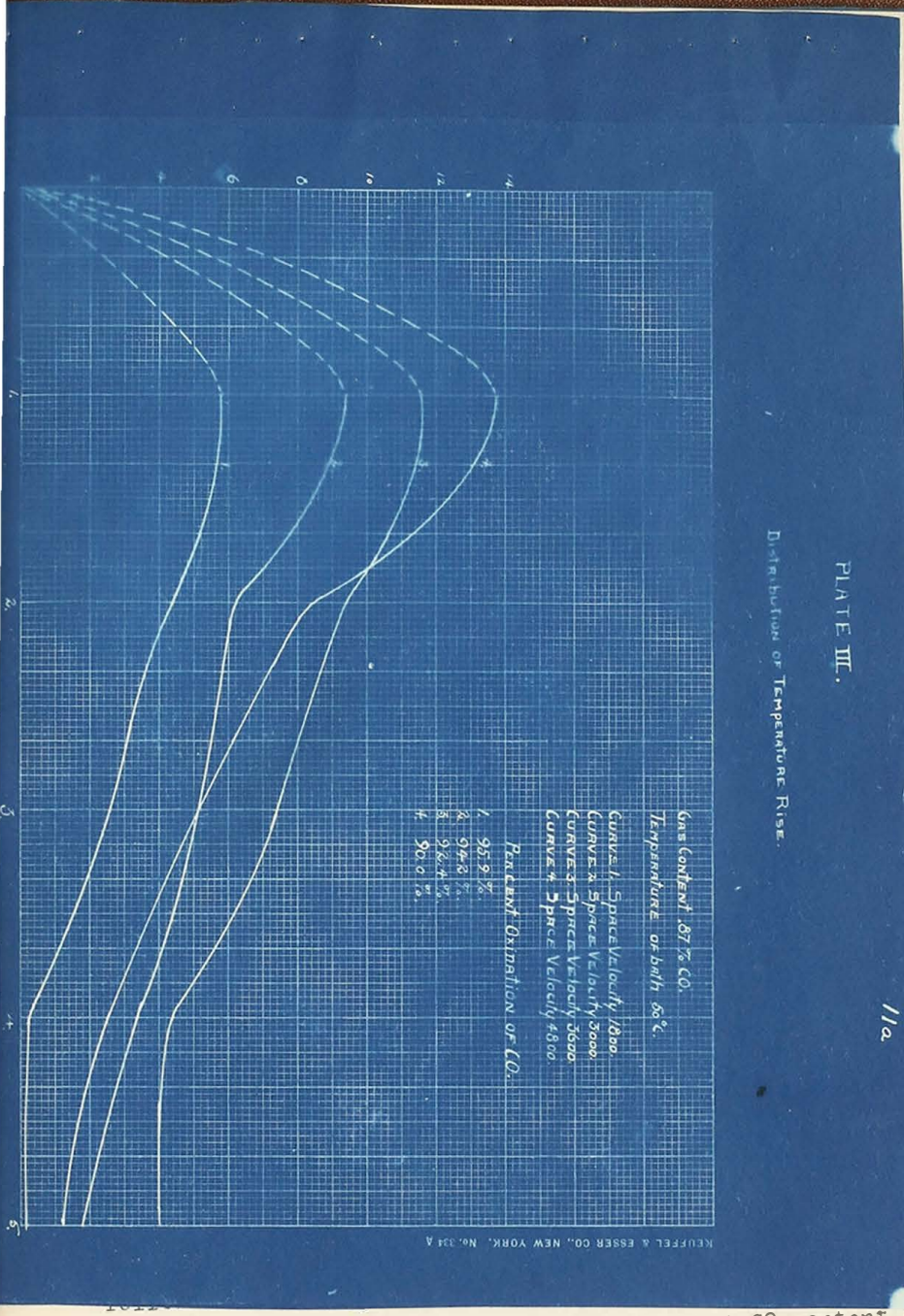
Temperature of thermostat as above. Space velocity 3600
Content of CO in air-gas mixture 0.87% Oxidation CO 92.4%
Arrangement of catalyst: as above.
Thermo-couple temperature difference in degree centigrade.

No. 1	No. 2	No. 3	No. 4	No. 5
11.6	9.4	7.5	4.2	4.1

Temperature of thermostat as above. Space velocity 4800
Content of CO in air-gas mixture 0.87% Oxidation CO 00.0%
Arrangement of catalyst: as above.
Thermo-couple temperature difference in degree centigrade.

No. 1	No. 2	No. 3	No. 4	No. 5
13.8	8.3	5.2	3.3	1.7

These results are shown graphically on the following page. This data fairly well establishes the effect of space velocity, showing that the maximum temperature rise is associated with maximum space velocity. It was thought best to determine the effect of varying CO content of the air-gas mixture, which follows;



2%

5%

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ure rise

is directly proportional to the CO content. A CO content of about 2% running dangerously close to the point at which hydrogen oxidizes. A re-arrangement of the catalyst was next tried.

Temperature of thermostat 50 degrees. Space velocity 3600
Content of CO in air-gas mixture 1.21% Oxidation CO 92.1%
Arrangement of catalyst: Pure catalyst thruout.
Thermo-couple temperature difference in degree centigrade.

No. 1	No. 2	No. 3	No. 4	No. 5
14.6	2.9	0,95	0.4	0.1

Temperature of thermostat as above. Space velocity 3600
Content of CO in air-gas mixture 1,33% Oxidation of CO 92.5%
Arrangement of catalyst: as above.
Thermo-couple temperature difference in degrees cebtigrade.

No. 1	No. 2	No. 3	No. 4	No. 5
16.8	1.7	0.6	0.3	-0.2

Temperature of thermostat as above. Space velocity 3600
Content of CO in air-gas mixture 1.63% Oxidation of CO 94.2%
Arrangement of catalyst as above.
Thermo-couple temperature difference in degree centigrade.

No. 1	No. 2	No. 3	No. 4	No. 5
17.4	3.95	1.5	0.8	0.55

Temperature of thermostat as above. Space velocity 3600
Content of CO in air-gas mixture 1.92% Oxidation of CO 94.5%
Arrangement of catalyst as above.
Thermo-couple temperature difference in degrees centigrade.

No.1	No. 2	No. 3	No. 4	No. 5
20.0	3.1	1.6	1.35	No 3

These results are represented graphically on the following page. It will be seen that the maximum temperature rise is directly proportional to the CO content. A CO content of about 2% running dangerously close to the point at which hydrogen oxidises. A re-arrangement of the catalyst was next tried.

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t.
e.

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ame.

6.8 1.2 1.0 0.7 0.0

Continued on following page

Temperature of thermostat 50 degrees. Space velocity 3600

Content of CO in air-gas mixture 1.92% Oxidation of CO 82.4%

Arrangement of catalyst: Diluted with brick 1 to 1 thrucut.

Thermo-couple temperature difference in degrees cebtigrade.
At end of five minutes.

No. 1	No. 2	No. 3	No. 4	No. 5
20.4	2.4	2.0	1.8	1.05

Temperature of thermostat 50 degrees. Space velocity 3600

Content of CO in air-gas mixture 1.92% Oxidation of CO same.

Arrangement of catalyst: as above.

Thermo-couple temperature difference in degrees centigrade.
At end of ten minutes.

No. 1	No. 2	No. 3	No. 4	No. 5
19.0	2.2	1.7	1.2	0.6

Temperature of thermostat 50 degrees. Space velocity 3600

Content of CO in air-gas mixture as above, Oxidation CO same.

Arrangement of catalyst: as above.

Thermo-couple temperature difference in degrees centigrade.
At end of 15 minutes.

No. 1	No. 2	No. 3	No. 4	No. 5
14.6	1.7	1.7	1.0	0.6

Temperature of thermostat 50 degres. Space velocity 3600

Content of CO in air-gas mixture as above. Oxidation CO same.

Arrangement of catalyst : as above.

Thermo-couple temperature in degrees centigrade.
At end of 20 minutes.

No. 1	No. 2	No. 3	No. 4	No. 5
6.8	1.2	1.0	0.7	0.0

Continued on following page

Temperature of thermostat 50 degrees. Space velocity 3600

Content of CO in air-gas mixture 1.92% Oxidation of CO 82.4%

Arrangement of catalyst: as above

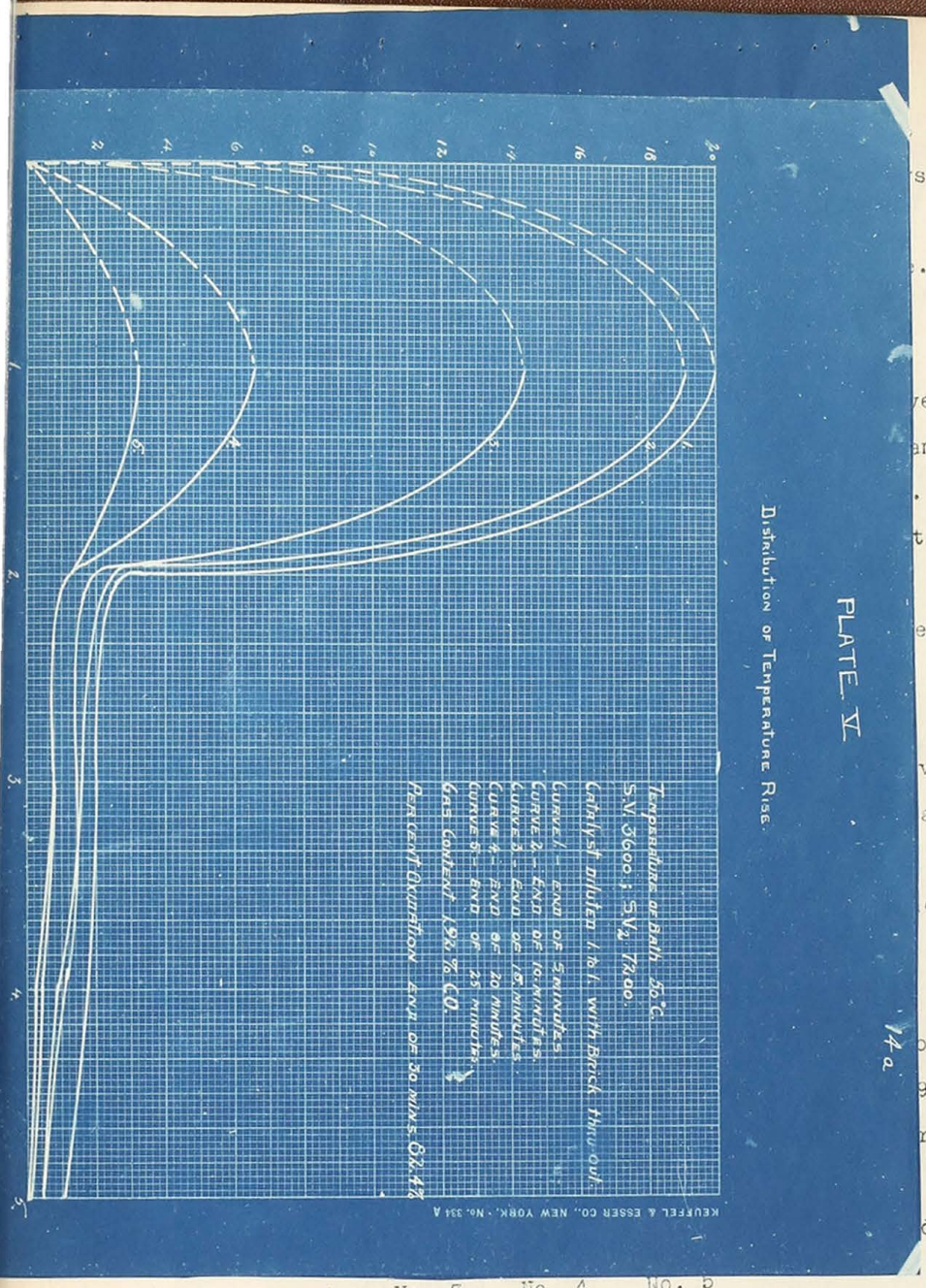
Thermo-couple temperature difference in degrees centigrade.
At end of 25 minutes.

No. 1	No. 2	No. 3	No. 4	No. 5
3.2	1.2	1.0	0.3	0.1

The results are shown graphically on the following page. It is seen that the catalyst rapidly looses efficiency with time, at the end of 30 minutes the oxidation being only 82.4%. A determination of the oxidation at the end of the other five minute periods were not made.

It was decided to vary the proportion of brick to catalyst thruout the catalyst tube in an attempt to distribute the temperature rise more evenly and also to determine the length of time necessary for the catalyst to give constant results.

It will be noticed in the graphic data recorded from this point of the work that the space velocitymis given in two terms, designated, S.V. and $S.V._2$. The first represents the space velocity as liters of gas per liter of tube content per hour of time, while the latter represents the space velocity as liters of gas per liter of catalyst per hour of time.



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No. 1	No. 2	No. 3	No. 4	No. 5
5.8	7.2	4.0	1.4	0.4

Continued on following page.

Temperature of thermostat 50 degrees. Space velocity 3600
Content of CO in air-gas mixture 0.63%. Oxidation of CO 98%
Arrangemnt of catalyst: First 3 thermo-couples half catalyst and half brick. Remainder, all catalyst.

Thermo-couple temperature difference in degrees centigrade.

No. 1	No. 2	No. 3	No. 4	No. 5
1.8	4.2	1.6	0.6	-0.8

Temperature of thermostat as above. Space velocity as above.
Content of CO in air-gas mixture as above. Oxidation CO same.
Arrangement of catalyst: First 1 part brick to 1 catalyst. Second, 2 brick to 5 catalyst. Third 1 brick to 4 catalyst. Fourth, 1 brick to 5 catalyst. Last, all catalyst.

Thermo-couple temperature difference in degrees centigrade.

No. 1	No. 2	No. 3	No. 4	No. 5
3.8	3.2	2.2	1.75	0.8

Temperature of thermostat as above. Space velocity as above.
Content of CO in air-gas mixture as above. Oxidation CO same.
Arrangement of catalyst: same as above.

Thermo-couple temperature difference in degrees centigrade.

No. 1	No. 2	No. 3	No. 4	No. 5
3.8	3.2	2.1	1.75	0.9

Temperature of thermostat as above. Space velocity as above.
Content of Co in air-gas mixture 0.86%. Oxidation of CO 99%
Arrangement of catalyst: First two half catalyst, half brick. Remaining three thermo-couples all catalyst.

Thermo-couple temperature difference in degrees centigrade.

No. 1	No. 2	No. 3	No. 4	No. 5
5.8	7.2	4.0	1.4	0.4

Continued on following page.

Temperature of thermostat 50 degrees. Space velocity 3600
Content of CO in air-gas mixture as above. Oxidation CO 99%
Arrangement of catalyst: same as above

At end of 10 minutes.

Thermo-couple temperature difference in degrees centigrade.

No. 1	No. 2	No. 3	No. 4	No. 5
4.0	8.6	5.8	3.0	1.75

Temperature of thermostat as above. Space velocity same.
Content of CO in air-gas mixture as above. Oxidation CO 99%
Arrangement of acatalyst: same as above.

At end of ten minutes.

No. 1	No. 2	No. 3	No. 4	No. 5
4.4	8.8	5.4	2.6	1.0

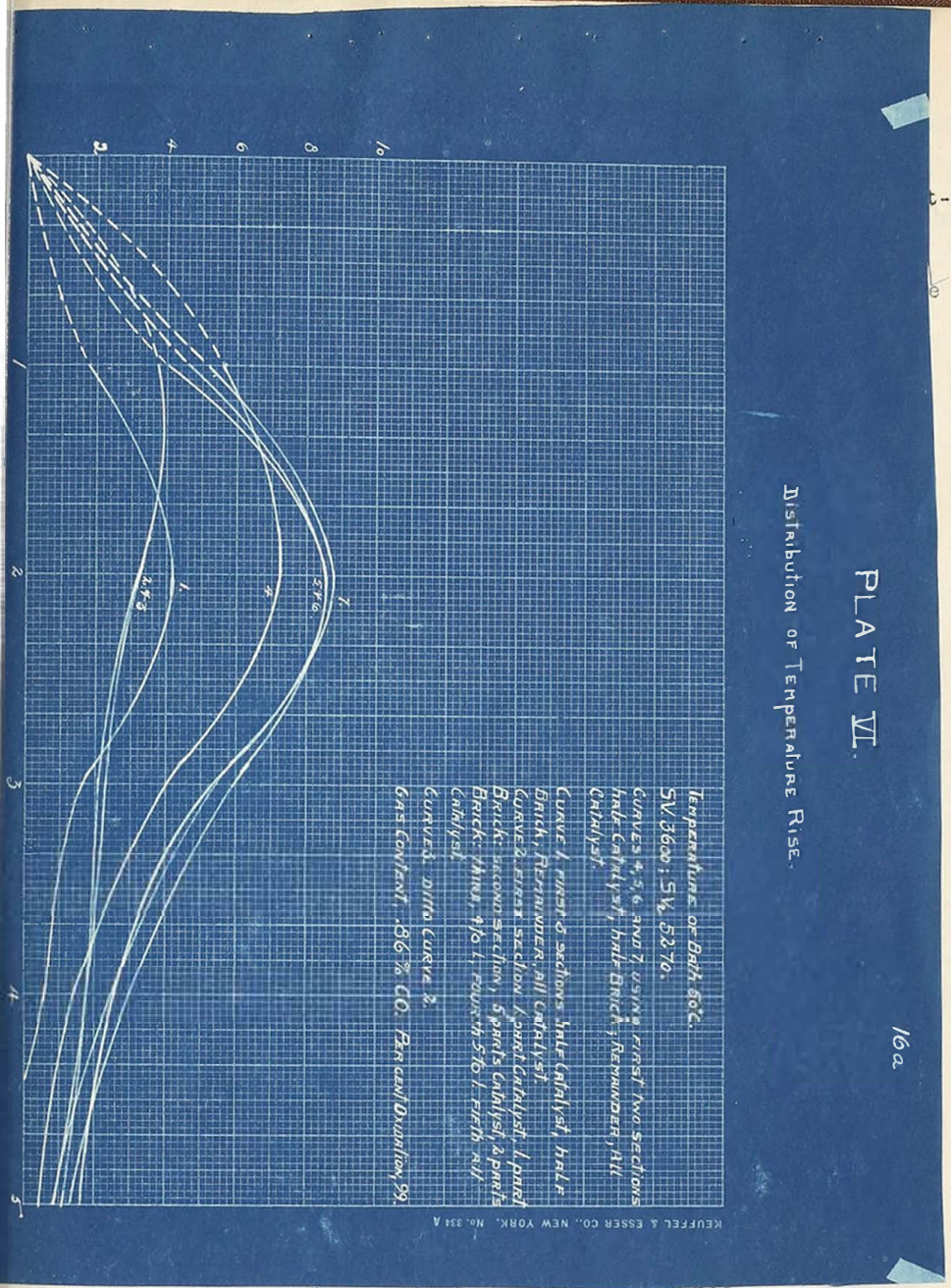
Temperature of thermostat as above. Space velocity same.
Content of CO in air-gas mixture as above. Oxidation CO 99%
Arrangement of catalyst: same as above.

At end of 5 minutes.

No. 1	No. 2	No. 3	No. 4	No. 5
5.2	8.8	5.6	2.6	1.2

These results are shown graphically on the following page. They show that with a catalyst arrangement as above constancy of results may be expected within 20 minutes. Here again the effect of CO concentration is well shown, there being almost twice as large maximum temperature rise for gas of 0.86% than for that of gas of 0.63%.

This study was continued with a different catalyst arrangement and allowing the run to continue for 45 minutes to test the life of the catalyst.



3.0 8.1 10.4

At end of 40 minute run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
3.0	7.8	10.5	6.1	1.9

These results are shown graphically on the following page.

Temperature of thermostat 50 degrees. Space velocity 3600. Content of CO in air-gas mixture 0.86% Oxidation CO 99.15% Arrangement of catalyst: First two thermo-couple 1 part catalyst i part brick. Remaining three couples all catalyst. Thermo-couple temperature differences in degrees centigrade

At end of 5 minutes run.

No.1	No. 2	No. 3	No. 4	No. 5
4.6	8.0	5.2	3.4	1.0

At end of 10 minute run (other conditions same as above)

No. 1	No. 2	No. 3	No. 4	No. 5
2.6	6.6	7.4	4.1	0.2

At end of 15 minute run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
3.2	7.8	5.8	3.4	0.9

At end of 20 minute run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
3.2	7.9	7.8	4.6	0.9

At end of 25 minute run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
3.0	8.0	8.7	5.7	2.0

At end of 30 minute run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
3.0	8.2	10.2	6.0	2.1

At end of 35 minute run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
3.0	8.1	10.4	6.2	2.0

At end of 40 minute run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
3.0	7.8	10.5	6.1	1.9

These results are shown graphically on the following page.

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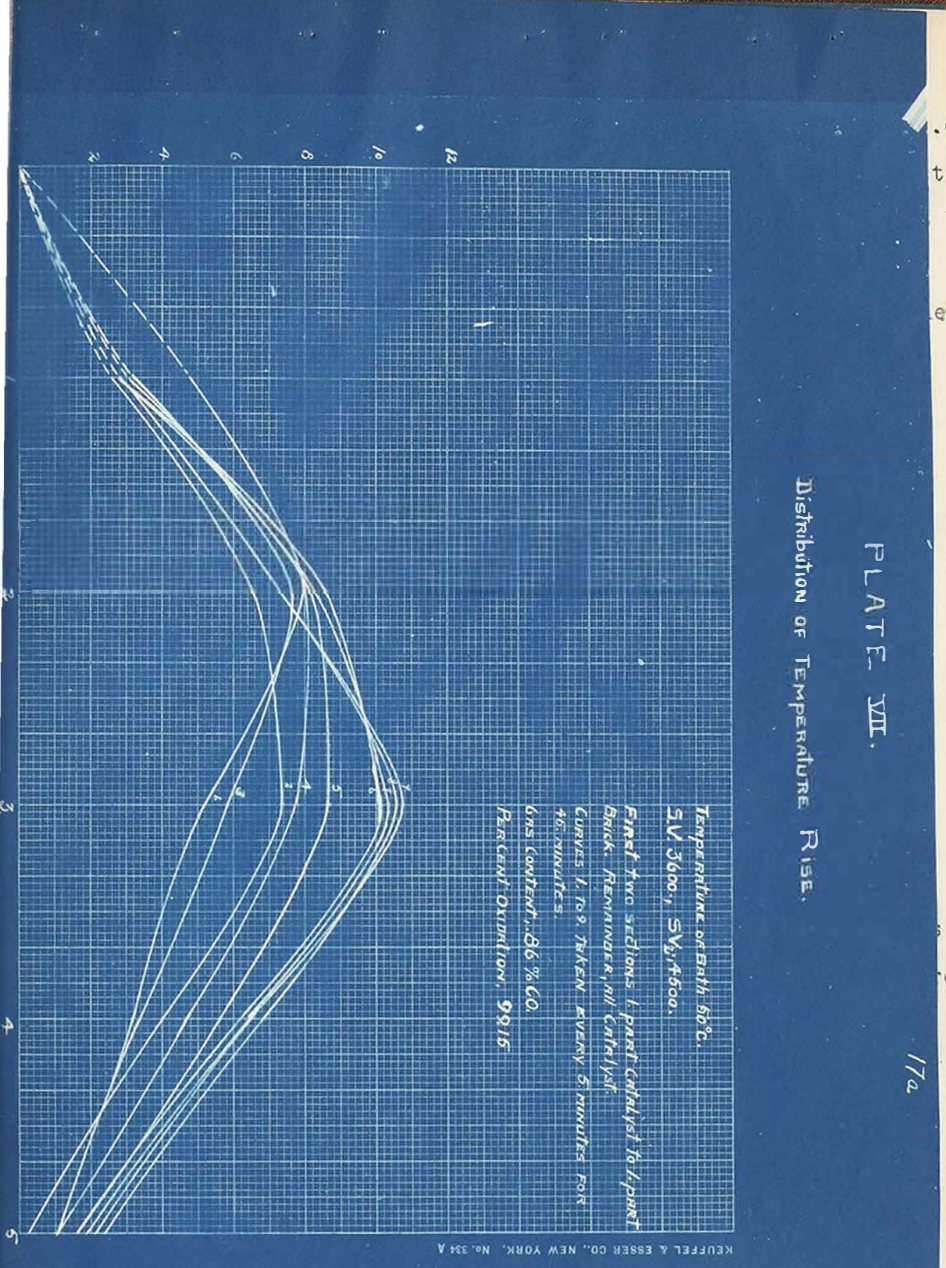

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At end of 60 minutes run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
6.1	9.6	6.9	5.6	3.2

Continued on following page.

Temperature of thrmostat 50 degrees. Space velocity 3600
Content of CO in air-gas mixture 0.86% Oxidation of CO 99.6%
Arrangement of catalyst; First couple three parts catalyst 1 part brick. Second and third couples 1 part catalyst to 1part brick. Remaining two all catalyst.

Thermo-couple temperature difference in degrees centigrade.

At end of 10 minutes run.

No. 1	No. 2	No. 3	No. 4	No. 5
11.1	10.2	4.8	3.8	2.2

At end of 20 minutes run(other conditions same as above)

No. 1	No. 2	No. 3	No. 4	No. 5
8.4	10.0	5.4	3.9	2.8

At end of 30 minutes run(other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
7.2	10.3	6.8	5.4	2.6

At end of 40 minute run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
6.8	10.0	7.0	5.2	3.0

These readings were continued for 30 minutes longer taking readings at intervals of 5 minutes with following results:

At end of 50 minutes (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
6.2	9.6	7.0	5.5	3.2

At end of 55 minutes run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
6.2	9.5	6.8	5.4	3.4

At end of 60 minutes run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
6.1	9.6	6.9	5.6	3.2

Continued on following page.

Temperature of thermostat 50 degrees. Space velocity 3600. Content of CO in air-gas mixture 0.86% Oxidation of CO 99.6% Arrangement of catalyst: First couple 3 parts catalyst 1 part brick. Second and third couples 1 part catalyst to 1 part brick. Remaining two all catalyst.

Thermo-couple temperature difference in degrees centigrade.

At end of 65 minutes run.

No. 1	No. 2	No. 3	No. 4	No. 5
6.0	9.8	6.6	5.2	3.1

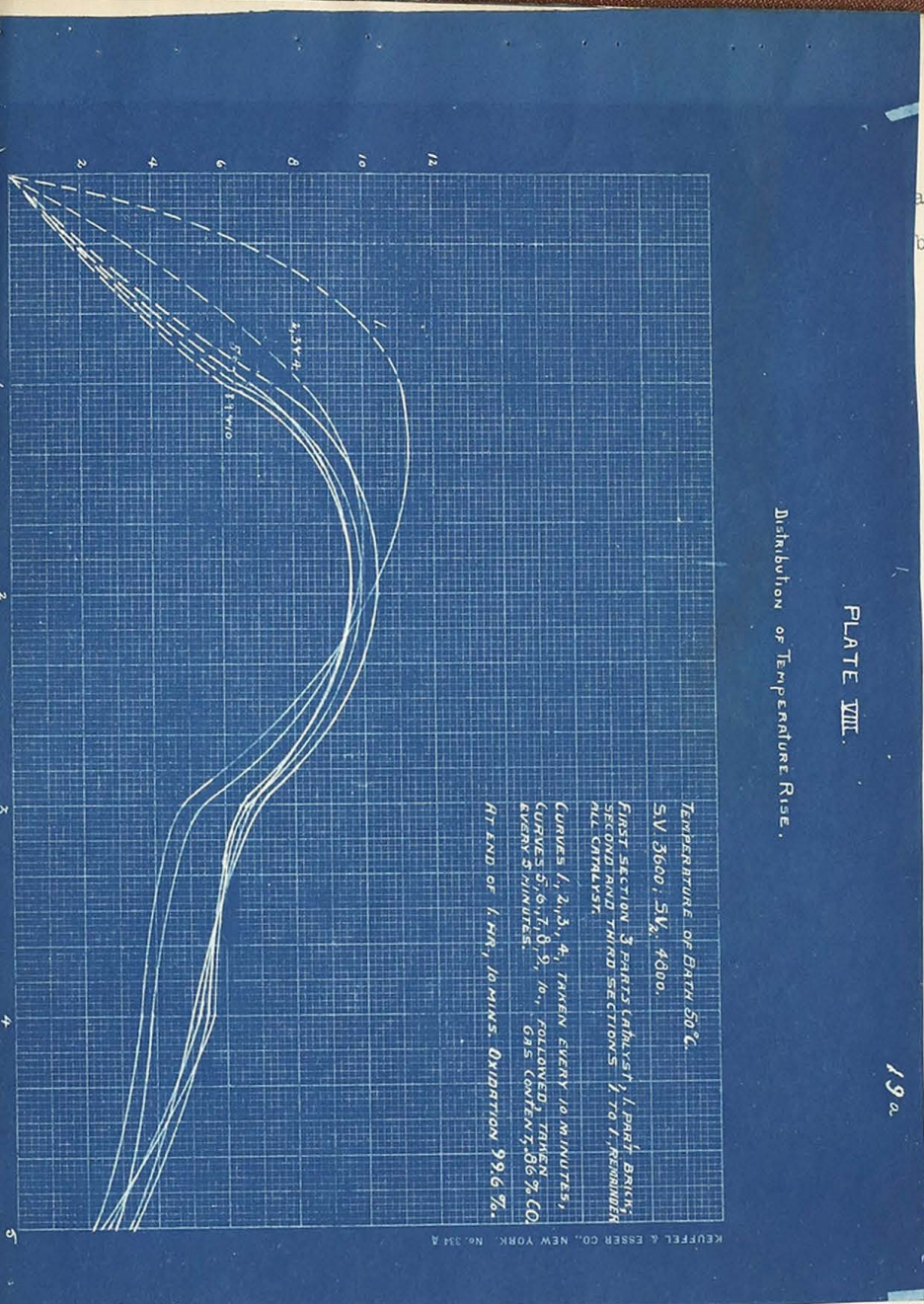
At end of 70 minutes run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
6.0	9.9	6.7	5.3	3.2

These results are shown graphically on the following page. They show that the life of the catalyst is quite efficient for the length of this run, an hour and 10 minutes, for the oxidation of CO at the end of that time was 99.6%.

The results are fairly constant after 20-30 minutes run, as is shown by the last six curves on the following page. This arrangement, then, of catalyst gives satisfactory oxidation, and constancy of results.

A new run was undertaken with a slightly different catalyst arrangement and a higher CO content of gas.



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temperature rise due to increased CO content of gas is dissipated. Thus it is thought possible to so arrange the catalyst as to fairly evenly distribute the temperature rise thruout the catalyst tube, accordingly a new arrangement was perfected and tried out.

Temperature of thermostat 50 degrees. Space velocity 3600. Content of CC in air-gas mixture 1.22% Oxidation of CO 98.9%. Arrangement of catalyst: First couple 3 parts catalyst to 1 part brick. Second, 2 catalyst to 1 brick. Third, 2 catalyst to 1 brick. Remaining two all catalyst.

Thermo-couple temperature difference in degrees centigrade.

At end of 5 minutes run.

No. 1	No. 2	No. 3	No. 4	No. 5
11.8	9.8	5.4	4.6	2.8

At end of 10 minutes run (other conditions same as above)

No. 1	No. 2	No. 3	No. 4	No. 5
11.1	10.2	5.8	5.0	3.8

At end of 15 minutes run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
9.4	10.8	5.8	5.0	3.0

At end of 20 minutes run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
8.4	12.1	5.8	5.8	2.6

At end of 25 minutes run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
8.0	12.1	5.7	5.6	2.8

At end of 30 minutes run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
8.0	12.0	5.8	5.7	2.8

These results are shown graphically on the following page. By arranging the catalyst as above a large proportion of the temperature rise due to increased CO content of gas is dissipated. Thus it is thought possible to so arrange the catalyst as to fairly evenly distribute the temperature rise thruout the catalyst tube, accordingly a new arrangement was perfected and tried out.

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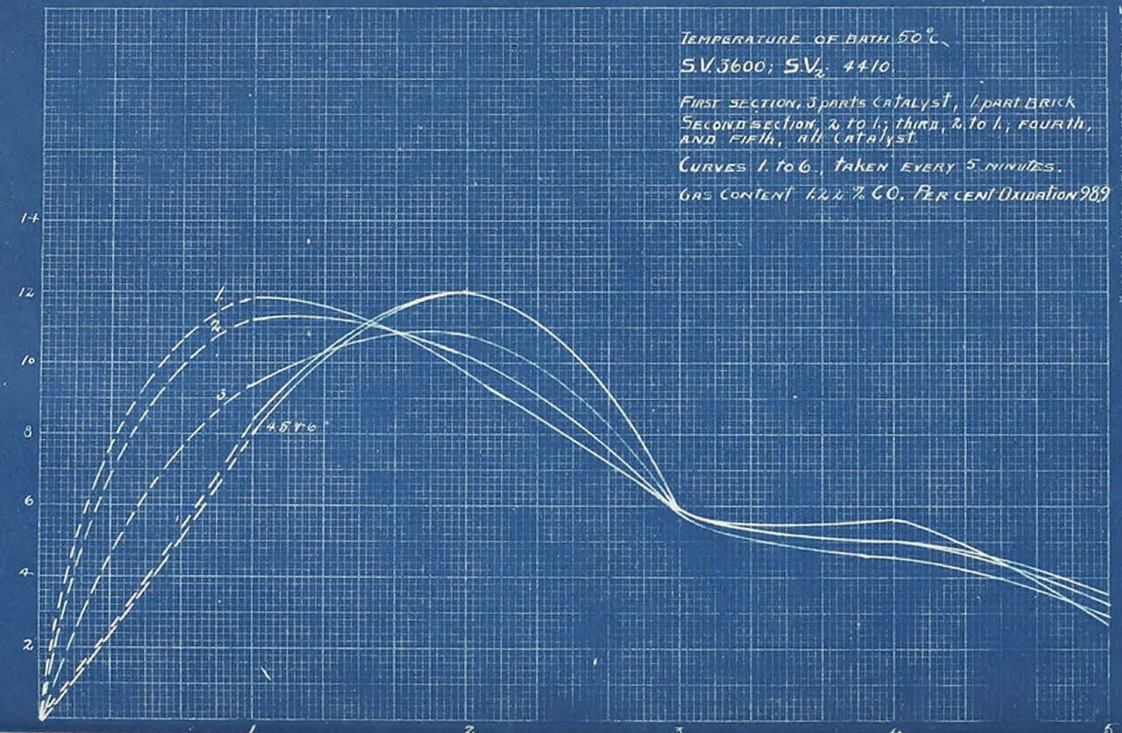
PLATE IX

Distribution of Temperature Rise.



Temperature of thermostat 50 degrees. Space velocity 3600.
Content of CO in air-gas mixture 0.90% Oxidation 99.3%
Arrangement of catalyst: First couple 3 parts catalyst to 1 part brick, with last ¼ inch all brick. Second, 2 parts catalyst to 1 brick. Third, 2 parts catalyst to 1 brick. Remaining two all catalyst.
Thermo-couple temperature difference in degrees centigrade.
At end of 30 minutes run.

No. 1	No. 2	No. 3	No. 4	No. 5
7.3	3.4	7.4	4.4	1.2

At end of 40 minutes run (other conditions same as above)

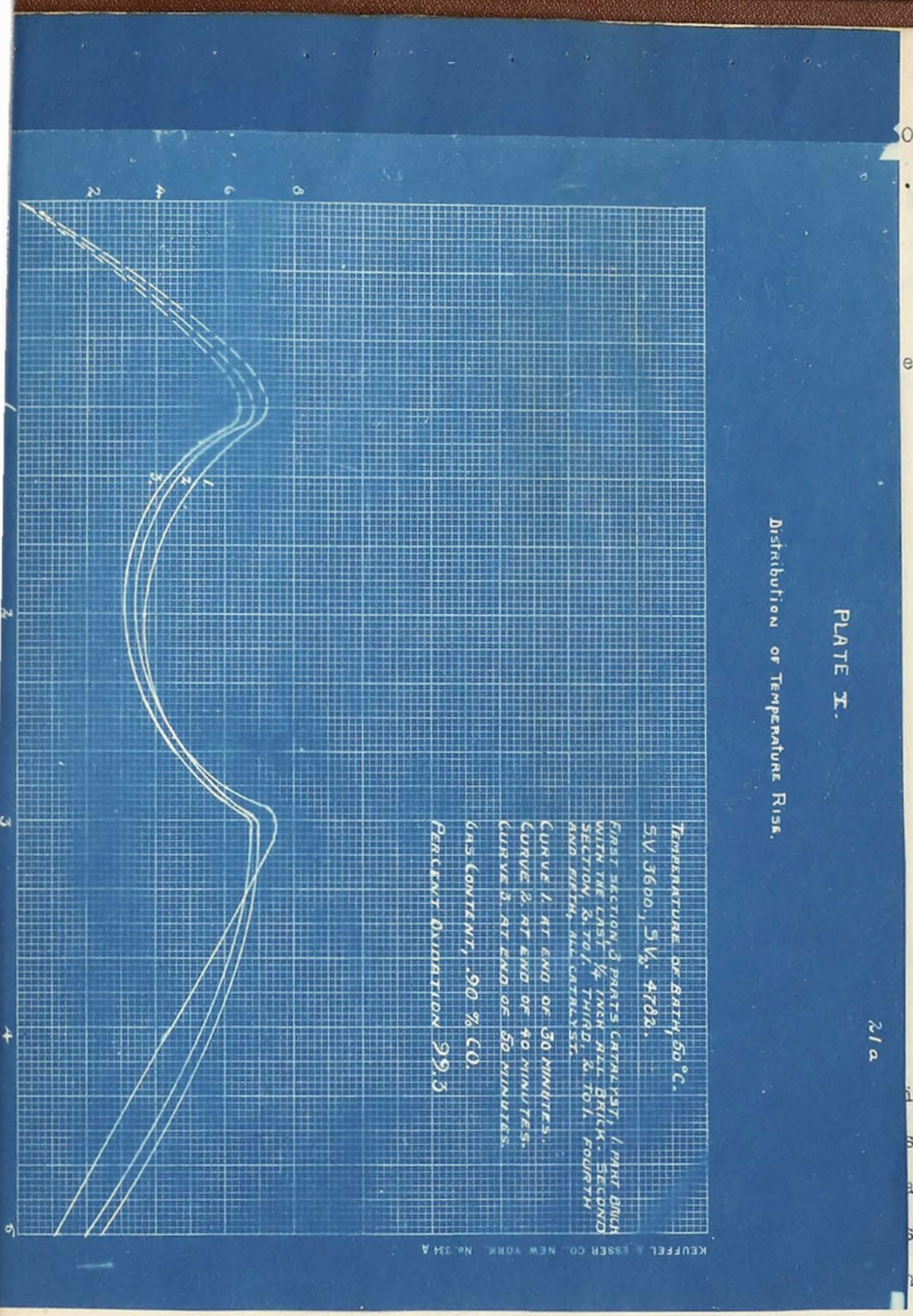
No. 1	No. 2	No. 3	No. 4	No. 5
6.9	3.2	7.1	5.8	2.2

At end of 50 minutes run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
6.8	3.0	7.1	5.6	2.0

These results are shown graphically on the following page. This data considered with the preceeding data shows that catalyst arrangement plays a major part in distributing the temperature rise. After half an hours run the results are always comparatively uniform. The efficiency in this case is very good, the CO being 99.3% oxidized at the end of an hours run.

In the light of these results a new arrangement of catalyst was resorted to, in the hopes of straightening out the temperature rise, other conditions being kept fairly uniform.



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first couple a little, should give a better result.

The efficiency in this case is not quite as good as in former cases.

Temperature of thermostat 50 degrees. Space velocity 3600. Content of CO in air-gas mixture 1.02%. Oxidation of CO 98.3%. Arrangement of catalyst: First couple 3 parts catalyst to 1 part brick. Second and third, 1 part catalyst to 2 brick. Remaining two all catalyst.

Thermo-couple temperature difference in degrees centigrade.

At end of 20 minutes run.

No. 1	No. 2	No. 3	No. 4	No. 5
6.9	2.8	3.0	3.0	2.2

At end of 25 minutes run (other conditions same as above)

No. 1	No. 2	No. 3	No. 4	No. 5
6.5	2.6	2.6	2.6	2.4

At end of 30 minutes run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
6.6	2.7	3.0	2.8	2.8

At end of 35 minutes run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
6.7	2.8	3.0	3.0	3.1

At end of 40 minutes run(other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
6.9	2.8	3.0	2.8	2.4

This data is shown graphically on the following page. These results show excellent uniformity of temperature rise in the last four couples, but the first couple remains somehat out of proportion. However, these results show that a catalyst arrangement somewhat similar to the above, possibly diluting the first couple a little, should give a better result.

The efficiency in this case is not quite as good as in former cases.

undertaken with a rearrangement of the catalyst in the light of previous results.

Temperature of thermostat 50 degrees. Space velocity 3600. Content of CO in air-gas mixture 0.78% Oxidation of CO 99.1%. Arrangement of catalyst: First couple 1 part brick to 1 part catalyst. Second, 2 brick to 1 and ¼ catalyst, third, 2 brick to 1 catalyst. Fourth and fifth couples all catalyst. Thermo-couple temperature difference in degrees centigrade.

At end of 20 minutes run.

No. 1	No. 2	No. 3	No. 4	No. 5
4.7	3.7	6.2	3.6	1.5

At end of 25 minutes run (other conditions same as above)

No. 1	No. 2	No. 3	No. 4	No. 5
4.2	3.7	5.4	3.2	1.4

At end of 30 minutes run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
3.9	3.4	6.0	4.2	2.2

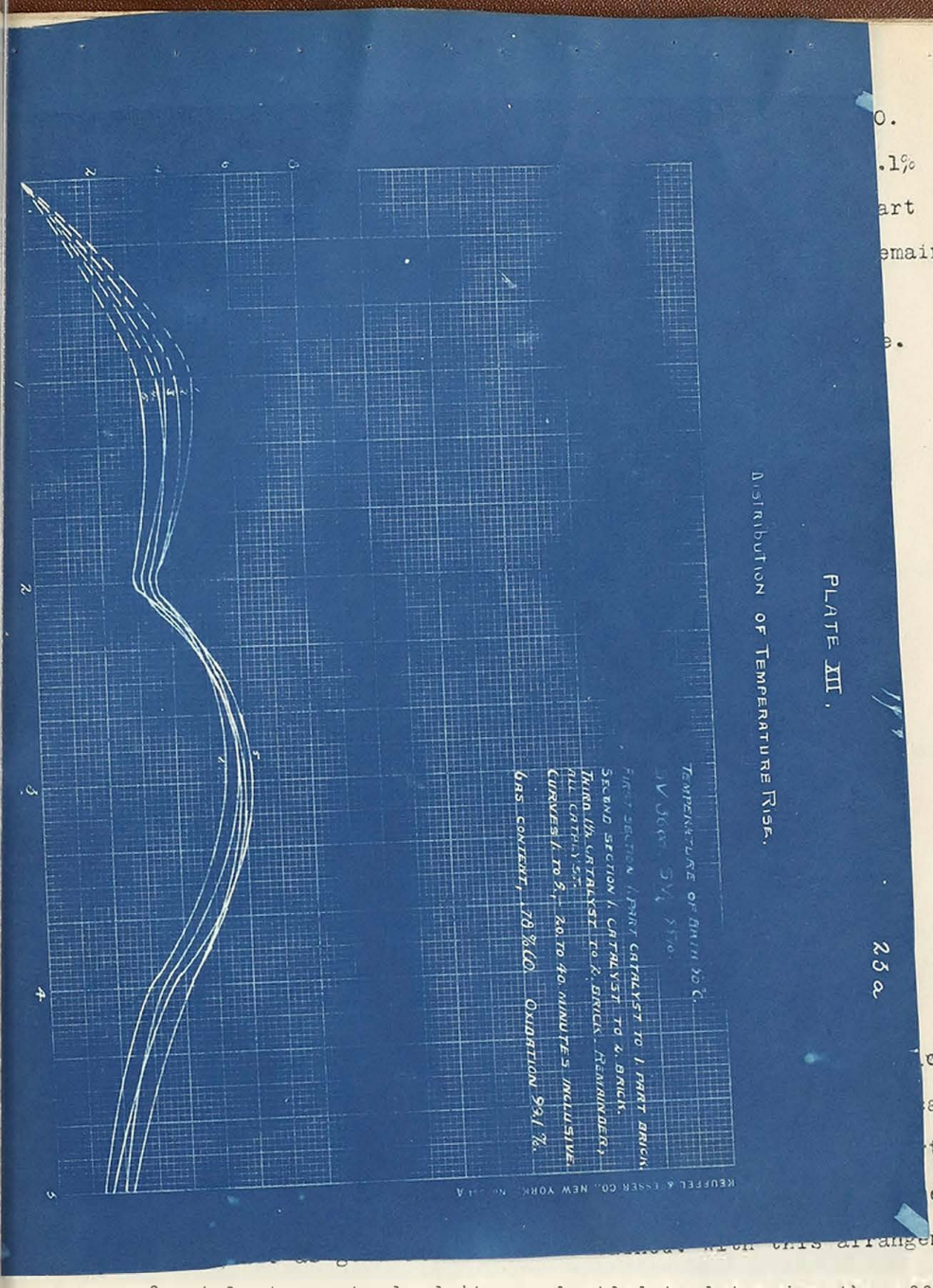
At end of 35 minutes run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
3.8	3.6	5.8	3.4	2.0

At end of 40 minutes run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
3.3	3.1	5.8	4.2	2.2

This data is shown graphically on the following page. While these results show two peaks for temperature rise, neither of them is as high as obtained heretogore. However, in practice this would be undesirable consequently a new determination was undertaken with a rearrangement of the catalyst in the light of previcus results.



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of catalyst as standard it was decided to determine the effect of different temperatures, space velocities and CO concentrations. The results of these determinations follow.

Temperature of thermostat 50 degrees. Space velocity 3600. Content of CO in air-gas mixture 0.96% Oxidation of CO 99.1% Arrangement of catalyst: First couple 1 part brick to 1 part catalyst. Second and third, 1 part catalyst to 2 brick. Remaining couple all catalyst.

Thermo-couple temperature difference in degrees centigrade.

At end of 20 minutes run.

No. 1	No. 2	No. 3	No. 4	No. 5
4.4	3.7	4.8	2.6	1.6

At end of 25 minutes run (other conditions same as above)

No. 1	No. 2	No. 3	No. 4	No. 5
4.2	3.7	4.8	2.6	2.2

At end of 30 minutes run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
3.6	3.7	4.8	2.6	2.4

At end of 35 minutes run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
3.6	3.4	4.6	2.4	2.1

At end of 40 minutes run (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
3.6	3.4	4.6	2.4	2.1

These results are shown graphically on the following page. The uniform distribution of temperature thruout the catalyst tube with the catalyst arrangement as above and for the particular conditions of temperature and CO concentration as above, seems to be quite as good as could be obtained. With this arrangement of catalyst as standard it was decided to determine the effect of different temperatures, space velocities and CO concentrations. The results of these determinations follow.

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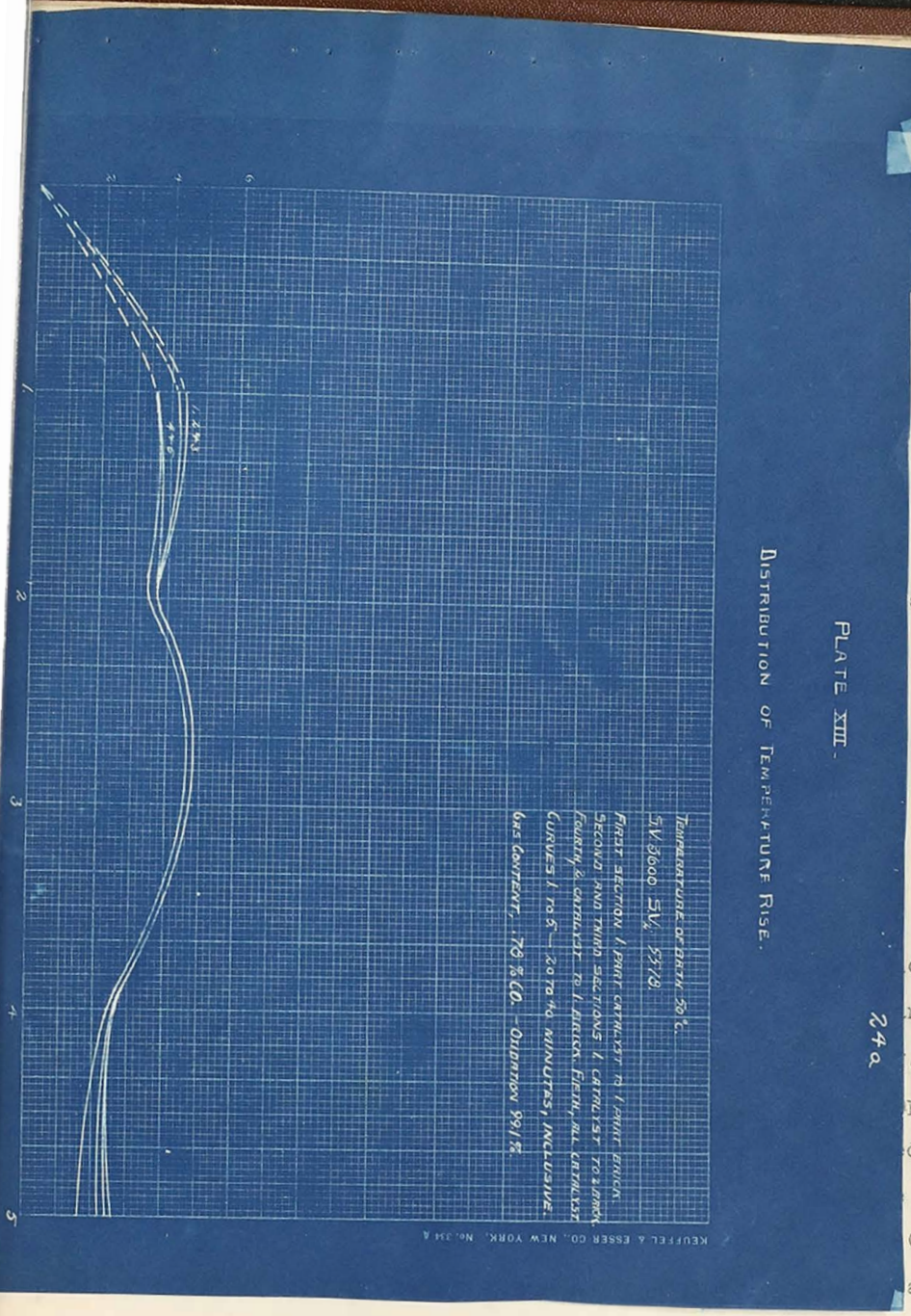


for in this case good oxidation was obtained at 50 and 60 degrees, but very poor oxidation at 40 degrees.

Temperature of thermostat varying. Space velocity 3600.
Content of CO in air-gas mixture 0.96% Oxidation varying.
Arrangement of catalyst: 1 part brick to 1 part catalyst for first couple. Second and third, 1 part catalyst to 2 parts brick. Remaining couple all catalyst.
Thermo-couple temperature difference in degrees centigrade.
Temperature of bath 50 degrees centigrade.

No. 1	No. 2	No. 3	No. 4	No. 5
5.4	3.6	4.9	1.1	0.5

Oxidation of CO 99.1%

Temperature of bath 50 degrees centigrade(other conditions smae)

No. 1	No. 2	No. 3	No. 4	No. 5
4.2	3.6	4.8	2.5	2.2

Oxidation of CO 99.1%

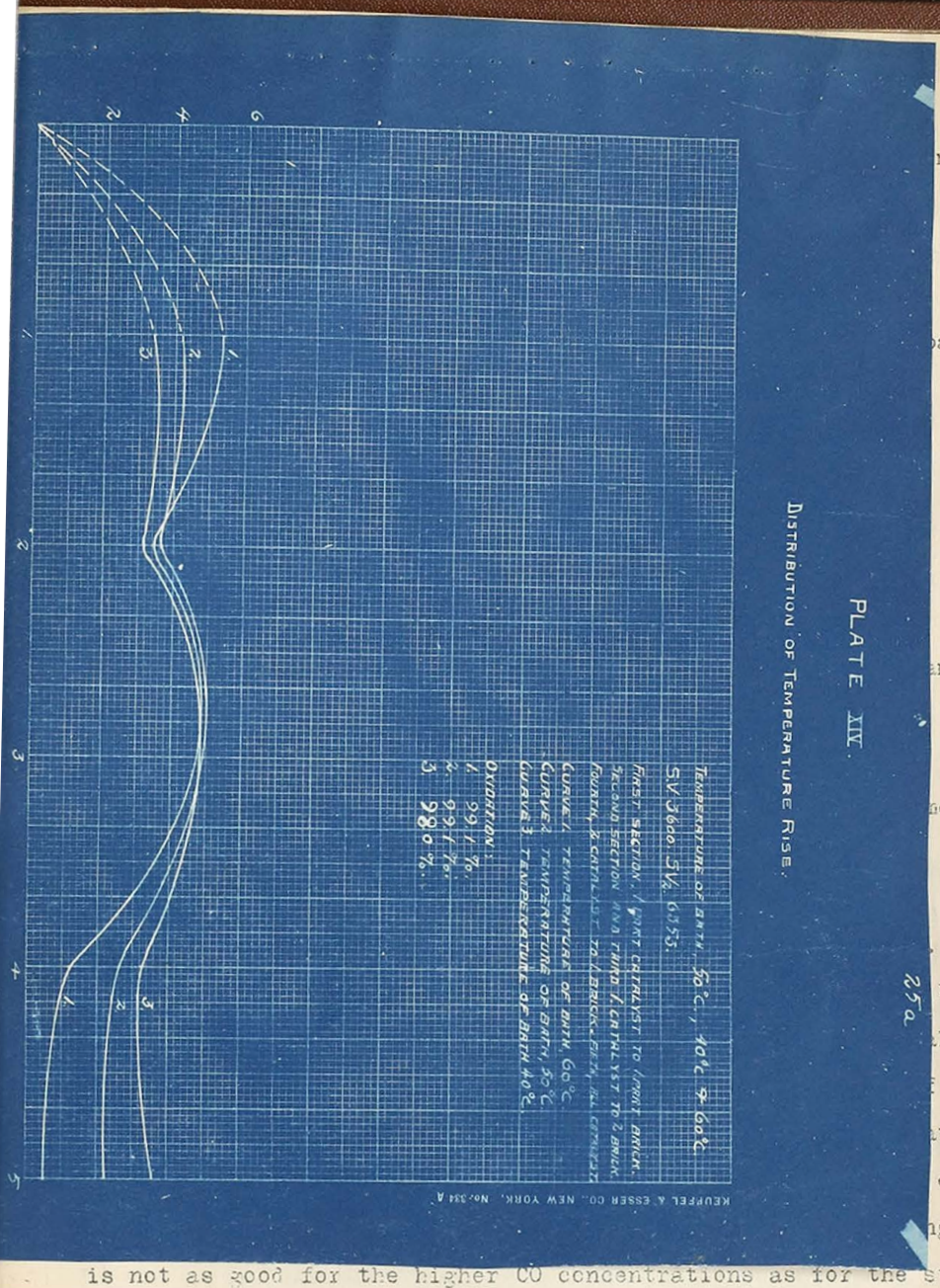
Temperature of bath 40 degrees centigrade (other conditions same)

No. 1	No. 2	No. 3	No. 4	No. 5
3.4	3.4	4.8	3.4	3.7

Oxidation of CO 98.0%

These results are shown graphically on the following page. They show that with a catalyst arrangement as above and at constant conditions of CO concentrations and space velocity, better results are obtained at 50 degrees, which is the temperature at which the conditions were originally standardized.

The standard curve is almost a mean between the two extremes of high and low temperature. The oxidation of the CO is somewhat dependent on the initial temperature of the catalyst, for in this case good oxidation was obtained at 50 and 60 degrees, but very poor oxidation at 40 degrees.



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is not as good for the higher CO concentrations as for the standard conditions.

Another set of determinations was undertaken in which the space velocity was made the variable. The results of this experiment are shown on page 27.

To further test this standard curve a series of determinations were carried out in which only the CO concentration varied. Temperature of thermostat 50 degrees. Space velocity 3600. Content of CO in air-gas mixture varying. Oxidation varying. Arrangement of catalyst: First couple 1 part catalyst to 1 part brick. Second and third, 1 part catalyst to 2 brick. Fourth, 2 catalyst to 1 brick. Last, all catalyst. Thermo-couple temperature difference in degrees centigrade.

CO content of gas 1.64% Oxidation of CO 98.6%.

No. 1	No. 2	No. 3	No. 4	No. 5
4.4	5.9	8.2	4.3	4.4

CO content of gas 1.31% Oxidation of CO 98.9% Other cond. same.

No. 1	No. 2	No. 3	No. 4	No. 5
3.3	4.6	5.4	3.2	4.4

CO content of gas 0.96% Oxidation 99.1% Other conditions same.

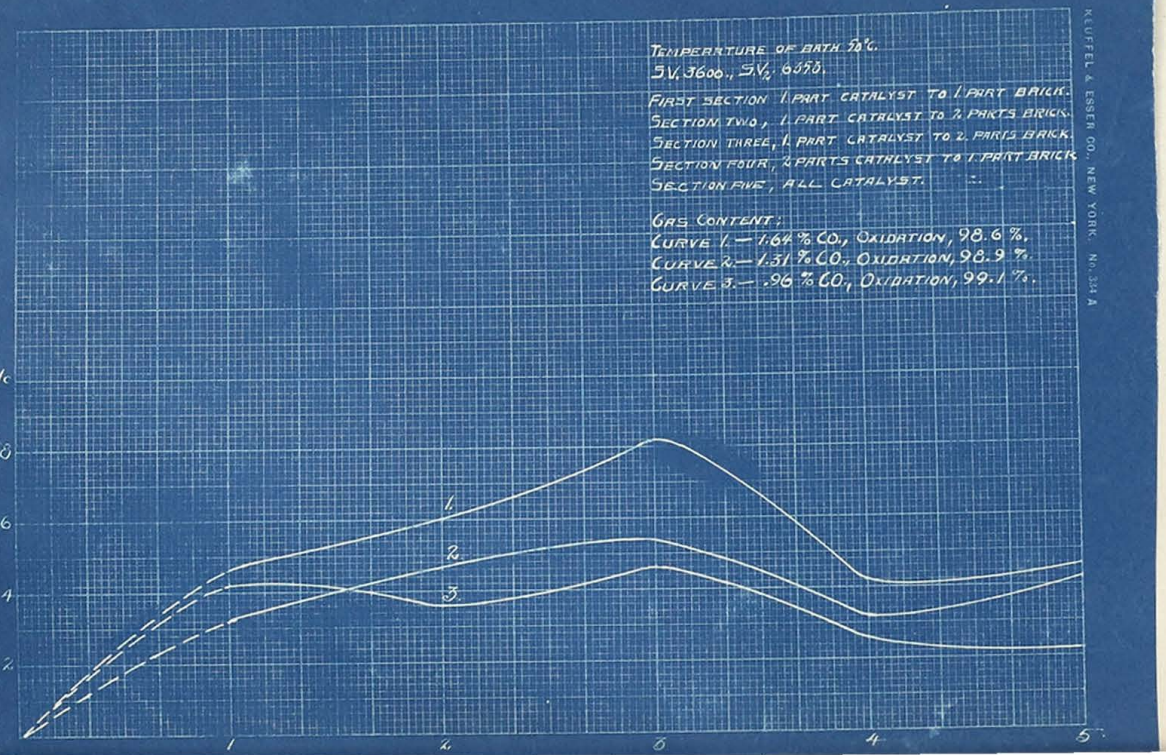
No. 1	No. 2	No. 3	No. 4	No. 5
4.2	3.6	4.8	2.6	2.2

These results are plotted on the following page. They show the same dependence on CO concentration that was shown by the first experiments. It seems that an arrangement of catalyst that will give uniform temperature rise for any given set of conditions of CO concentration will vary with a maximum temperature rise above or below the standard curve, depending on the CO concentration. The oxidation for this particular catalyst arrangement is not as good for the higher CO concentrations as for the standard conditions.

Another set of determinations was undertaken in which the space velocity was made the variable. The results of this experiment are shown on page 27.

PLATE XV.

Distribution of Temperature Rise.



Temperature of thermostat 50 degrees. Space velocity varying. Content of CO in air-gas mixture .978% Oxidation of CO 99.5% Arrangement of catalyst: First couple 1 part catalyst to 1 part brick. Second and third, 1 part catalyst to 2 brick. Fourth, 2 catalyst to 1 brick. Fifth, all catalyst.

Thermo-couple temperature difference in degrees centigrade.

Space velocity 2000.

No. 1	No. 2	No. 3	No. 4	No. 5
4.4	1.4	1.2	1.0	-0.3

Space velocity 3600.

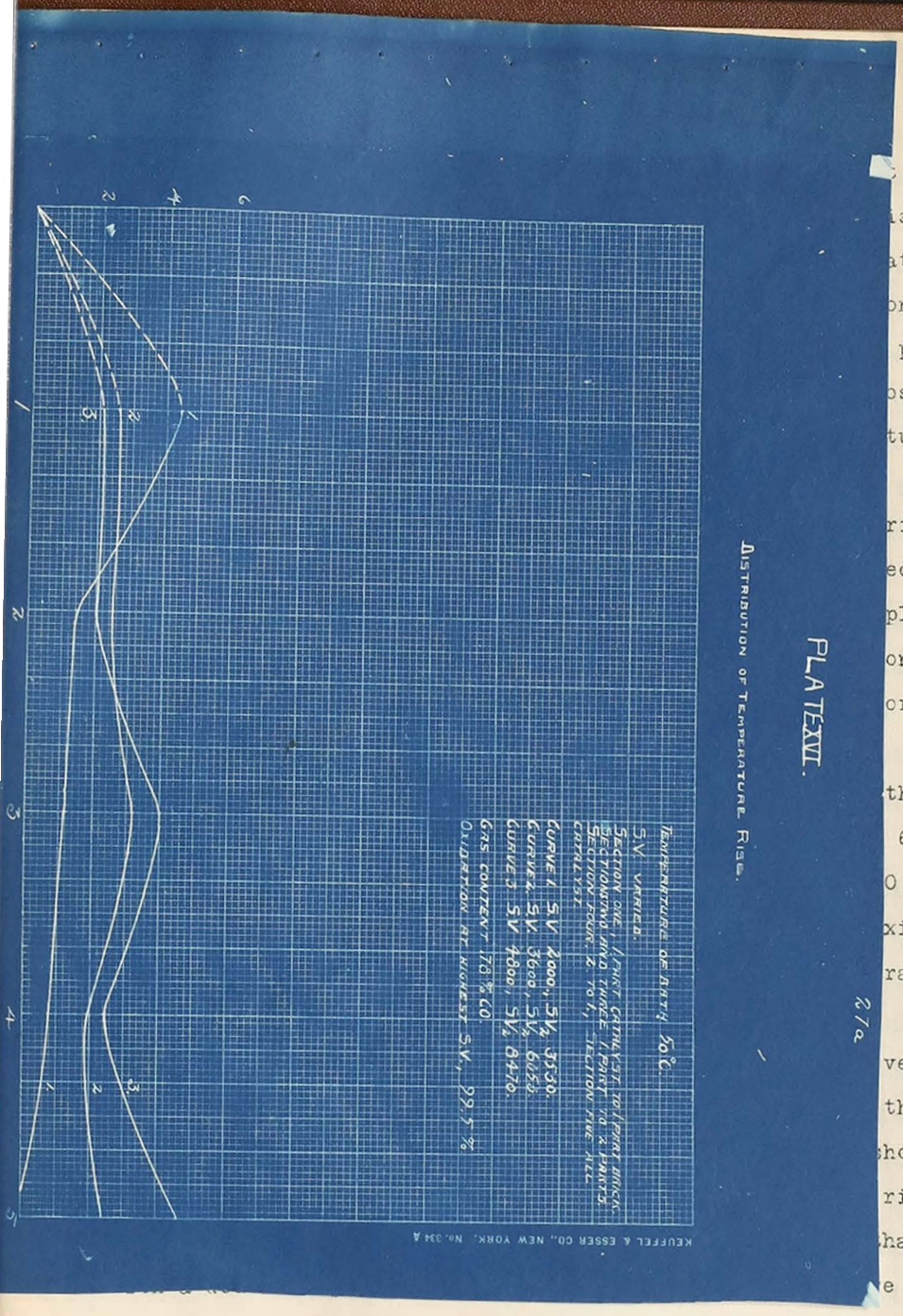
No. 1	No. 2	No. 3	No. 4	No. 5
2.6	2.5	3.2	2.0	2.4

Space velocity 4800.

No. 1	No. 2	No. 3	No. 4	No. 5
2.1	2.0	4.0	2.4	4.6

These results are shown graphically on the following page. The effect of space velocity is quite marked. While within the limits of this experiment the oxidation was quite satisfactory, the maximum temperature rise in both cases other than the standard curve, was too great. Here again the standard curve is nearly a mean between the higher and lower space velocities.

A discussion of the results obtained in the entire investigation begins on the following page.



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DISCUSSION.

In a study of a given problem in which the result sought is worked out by a progressive variation of one condition, it is, of course, always well when possible to fix other variables so that a change in experimental results will be in terms of one condition in question. Thus the work recorded graphically in the first 4 plates (pages 9a thru 12a), was conducted in order to ascertain the most suitable space velocity and the lowest temperature at which actual, or very nearly, 100% oxidation of CO occurs.

The results shown on plate 1 were obtained primarily in order to indicate the general character of the curve obtained by plotting temperature of elevation against successive therm-couples thruout the catalyst tube. This shows that the maximum oxidation takes place around the first couple, or within the first inch or two of the catalyst.

Passing to plate 2 we see that the oxidation of the CO approaches 100% as the temperature is varied between 35 and 60 degrees. There is very little difference in the oxidation at 50 and at 60 degrees, and due to the fact that at 50 degrees the monoxide is very nearly completely converted to the dioxide, this temperature was fixed for subsequent experiments.

It was to be expected that an increase in space velocity would mean an increase in temperature within the tube and this fact is established by data shown on plate 3. These results show, further that with space velocities here used, the temperature rise is very closely directly proportional to the space velocity; that is, that with a doubled space velocity the elevation of temperature is doubeled. The oxidation is slightly less for the higher space velocities.

In order to gain some idea as to the effect of a change

in gas compsoition upon the temperature within the tube, experiments were carried out giving the results shown on plate 4, using 50 degrees as fixed temperature and selecting 3600 as a suitable space velocity. Here we find, as would be expected, an increase in percentage of CO means a corresponding increase of temperature. With a gas of around 2% CO content it is noticed that the temperature around couple #1 runs dangerously high. Here again the fact is noted that oxidation is very nearly completed in the first inch or two of the catalyst. The oxidation, we see, is more efficient with the higher CO content which is probably due to the higher temperature generated with these mixtures.

The foregoing work was carried out largely to gather together general information and from a study of these data a temperature of 50 degrees and a space velocity of 3600 was decided upon for further research. Beginning with plate 5 are results obtained in an effort to evenly distribute the temperature rise within the tube.

The curves on plate 5 present an accentuated example of a peculiarity which we can not yet explain. Namely, that in all cases where the catalyst has been diluted the temperature elevation reaches constancy only after several minutes (in this case 25 min.) Usually however, 10 minutes suffices. In this instance the catalyst was diluted thruout the inert brick of particles of the same size as the catalyst, and in the proportion of 1 to 1. Consideration of curve #5 (plate 5) shows distinctly the effect of the brick is quite marked. However, repeated runs convinced us that with such a dilution a 100% oxidation could not be obtained and for this reason the tube was emptied and refilled as designated in plate 6.

These results were quite satisfactory from the standpont of completeness of oxidation. In curve #1 the maximum oxidation

was shifted from the first to the second couple; as a result it was thought feasible to have a dilute mixture at the first part of the tube and progressively increase it toward the end, in an attempt to shift a part of the oxidation toward the far end of the tube. Such an arrangement still gave the major part of oxidation to the first part of the tube so that another arrangement was tried as indicated on this plate, giving curves #4, 5, 6, and 7. Curve 4 was obtained after five minutes run; the other three at five minute intervals thereafter. Here we realized the dissatisfaction of such an arrangement because of the marked maxima around the second couple.

The curves shown on plate 7 are of conditions similar to those of #4, 5, 6, and 7 on the preceeding plate, except that a new gas mixture had been made up. The nature of the curve is the same.

Probably because we had been so accustomed to see a curve high around couple 1, and since in the curves of plates 6 and 7 this maximum had been shifted to around couples 2 and 3, we decided to increase the catalyst concentration around couple 1 thus making it 3 parts catalyst to 1 part brick. (see plate 8 for complete arrangement). This gave a high point again to the first part of the tube with a gradual decrease towards the other end. In an attempt to put the elevation of temperature of couples 2 and 3 up around that of couple 1, the arrangement shown in plate 9 was tried.

Curves 4, 5, and 6, which are the ones truly representative of this arrangement show a distinct maxima again. This made about the fourth time that in different arrangements the result had been simply to shift the high temperature point from couple 1 to 2 or to 3 as the case may be. Thus in our next arrangement it was decided to place a quarter of an inch all brick between couple 1 and 2. The complete arrangement is shown in plate 10, which is typically

illustrative of the distinct effect of a slight variation in the mixture. Between couples 1, and 2. the curve takes a deep drop, and due to this cooling, number 3, does not register very highly; for the most part, only the heat generated at this point-very little heat of previous points being mechanically swept along to number 3.

While this was encouraging, still the curve is far from being straight, and accordingly improvement was sought by changing the disposition of numbers 2. and 3. from 2 parts catalyst to 1 of brick, to 1 of catalyst to 2 of brick. (See plate 11) The results from this were quite satisfactory with the exception of the first part, and showed clearly for the first time that the ratio of catalyst to brick around the first couple would have to be lessened. Thus as is seen in plate 12. we next placed in the first section of the tube a 1. to 1. catalyst-brick mixture. In the third section of the tube the catalyst-brick ratio was raised to 1.5 to 2. since, because number 1. was being decreased, we figured so much more CO would be left for the further sections to oxidize this increase of catalyst in number 3. would be necessary. The results show, however, that this ratio around nomber 3, caused the maxima to shift to this point; not an abrupt peak, true, but on the whole, giving a curve upon which one might improve.

The ratio of 1 to 1 (catalyst, brick) for the first section seemed to be good enough. Similiarly, a ratio of 1 to 2 (catalyst, brick) for the second had proved satisfactory. However, a 1.5:2 ratio seemed a little too high for couple 3 (see plate 12), so a 1 to 2 ratio was substituted as shown in plate 13. For fear this decrease might shift a high point to couple 4 this section was replaced by a 2 to 1 ratio (catalyst, brick) instead of all catalyst.

Since couple 5 had always been low eneough we did not change it.

This arrangement, as is seen from the curves, gave very good results. The temperature rise around couples 1 and 3 are quite close and only slightly lower around 2. Couples 4 and 5, of course, are a little lower still, but in the whole tube no point was higher than 4.6 degrees after 40 minutes run (see page 24). It was concluded that this arrangement was quite satisfactory, and could not be improved upon, because so often a slight change produces so marked an effect. The ratios are simple, only the whole numbers 1 and 2 being involved; the mixtures easily and quickly prepared.

It is realized that this arrangement gives a good curve only for the fixed conditions of temperature and space velocity and percent of CO as specified, and undoubtedly would vary with variance of the conditions. The important fact established, however, is that by a study of results brought about by different mixtures, an arrangement can be developed which will give, very nearly, a straight line. To ascertain just how this mixture would act towards a variation of space velocity, temperature and CO content the work graphically recorded in plates 14, 15, and 16 was carried out. The results show in plate 14 are just as were expected. The highest temperature caused a maxima at this point; the medium temperature being between these two. This plate also shows that the curve highest at the first part of the tube will be lowest at the last part, and vice versa.

At this point it might be well to note the fact that even at 40 degrees the oxidation is very good, which is not congruent with results obtained in the first few determination (see plates 2 and 3). This is explained, we think, in that during the first part of this work when analyzing a sample after its passage over the

catalyst, we failed to completely clean cut the calcium chloride and phosphorus pentoxide tubes by draining an air current thru for a sufficient length of time. Thus if an analysis had been made from the CO-air storage tank and followed by an analysis of gas after passing it thru the catalyst tube, the oxidation, or efficiency, of the catalyst would register a little less than it really was. We conclude, then, that in many cases the oxidation was really better than that recorded.

The results with variation of gas composition as shown in plate 15 are in line with logical prediction; a higher CO content acting analogously to those of plate 4, the lessened effect being due to the catalyst arrangement.

The space velocity was varied as shown in plate 16, It was to be expected that a low space velocity would give a higher oxidation in the first part of the tube, and a high space velocity in the last part. Curves 1 and 3 show this to be the case. A medium space velocity, curve 2, falls a mean between curve 1 high, and curve 3 low.

Lamb, Scalione and Edgar did some work on the effect of moisture on Hopcolite. (Jour. Amer. Chem. Soc. April 1922.) They worked with a gas containing 50 mm. water. They have shown that moist CO-air-H_2 mixtures require much higher temperatures for oxidation than if the moisture were absent. Too, it may be noticed that if the space velocity is plotted against the temperature at which 100% oxidation occurs (data p 747, 1922 Jour.) a very nearly straight line is obtained, which tends to flatten slightly at high (30000) space velocities. At space velocities up to 18000 an increase os space velocity of 1000 means an increase of 1.66 degrees in temperatur of the bath in order to secure 100% oxidation. In our disquisition we filled the tube with catalyst without dilution and used a CO-air mixture containing 4. mm. water, which of course, is conveniently had by bubbling the gas thru an ice-tower. First however, we made a

run of the gas thru the usual drying process and noted the curve. Then we switched the gas current from the drying towers to the ice-water tower. The result was instantaneous. The galvanometer deflection immediately dropped considerable, and an analysis of a sample showed that the oxidation had fallen correspondingly low. In order to ascertain at what temperature the catalyst would function efficiently under these conditions, the temperature of the bath was raised from 50 degrees to 70 degrees. At this temperature the oxidation, and therefor the resultant curve, was identical with that obtained for the same gas with no water vapor. The thermostat temperature was now slowly dropped while the flow of gas continued. Oxidation remained complete until 65 degrees was reached, at which temperature it decreased with the cooling of the bath.

It seems then from our results, and those of others, that moisture simply necessitates a higher temperature of the bath; that when the bath is hot eneough to cause the Hopcolite to function efficiently, the moisture des not otherwise make itself objectionable. Thus there seems to be no reason, if it is known approximately how much water will be present, why a catalyst-brick disposition can not be worked out which will evenly distribute the temperature within the catalyst tube.

CONCLUSIONS.

1. It is shown that the temperature rise within the catalyst tube is directly proportional to the space velocity; that it is proportional to the temperature of the bath and to the CO content of the gas, and that when the CO content approximates 2%, using pure catalyst, the maximum temperature rise within the catalyst tube approaches very closely the point at which oxidation of hydrogen begins.

2. It is shown that, given a definite set of conditions the catalyst may be diluted, and so arranged, as to maintain a practically uniform distribution of temperature rise thruout the catalyst tube.

3. Water vapor poisons the catalyst and necessitates a higher temperature of the thermostat for complete oxidation, without necessitating a re-arrangement of the catalyst in order to maintain an even distribution of temperature rise within the catalyst tube.

FINIS.