



THE EVEN DISTRIBUTION OF TEMPERATURE RISE WITHIN THE CATALYST TUBE IN THE OXIDATION OF CARBON MONOXIDE BY MEANS OF HOPCALITE (CuO-MnO₂) BY

HENRY EDWIN SHIVEN











A Thesis presented to the Academic Faculty of the University of Virginia in candidacy for the degree of Master of Science.

The .

170

a state of the

April 1

 $\overline{\sigma}_{f}$



THE EVEN DISTRIBUTION OF TEMPERATURE RISE WITHIN THE CATALYST TUBE IN THE OXIDAT-ION OF CARBON MONOLIDE BY MELNS OF "HOPCOLITE" (Cuo-MnO₂).

1.

This investi ation deals with a very important part of the general problem: "The removal of carbon monoxide from watergas' 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 mixin 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- as hydroren is prepared in two standard ways, and is delivered with the followin composition, accordin: to the method of preparation: 65% H₂, 1% N₂, 32% CO₂, and 2-3% CO; or 51% H₂, 17% N₂, 29% CO₂, and 2-3% CO. It is saturated with water vapor at about 40 degrees and may contain, in addition, small amounts of H₂s, 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 3 s re 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 f ct 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 exidation or hydrotenation of CO to CC_2 or to CH4, respectively. In processes involving the latter, three mols of H₂ are required for each mol of CO, and CH₄ 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 CO₂, at high temperatures, a relatively inactive catalyst may be used and only a small excess over the theoretical requirement of oxy on 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 right and the cases must be purified of volatile metalloids

4.

· . .

the for a roll of the formation of the second term of term of term of term of term of term of terms of term of terms of terms

instro anation of G to Org or to Car, republicate, in production of the weights the Latter, there and of by addicating the state one of the and Org restalts economistics in the orgetic equivity periods for controls. However, there produces a convert event wery excluded the controls and the react of const none, and the state-weight the of the astilized as with the firsteelory.

In the outstand, when outstand, of the part of the second of a stall back in the second of a stall back in the outstand of the second of the start back in the second of the start back in the second of the start of the second o

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 sonsitive 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 mas. 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 oxymen, for the oxidation of CO. The oxidation of CO must be carried out in the presence of a large excess of CO_2 . The spacevolume-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_p . While these substances

3.

en the state

mand and the second second second at the second second second second second second second second second second

4

· Contraction with the failed of the

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 cxygen. In order that these exides act catalytically, it is necessary that they be rapidly reoxidized to their former state by the exygen present in the tas. It is further necessary that these reactions take place rapidly in order to function at high space velocities.

4.

The following table from Fay, sutherland and Ferguson in Poly. Eng. 10;72 (1910), shows the action of some of the more

ommon oxid	es.		
Oxide	Initial Temp in Detrees C with CO	Initial Tem) Degrees C w 150	p in ith H ₂ Remarks Direction Pb ₂ O ₃ with HNO ₃
2002		170	
Pb203	150	165	
CeO	155	100	Oxidation of CO by
Co.O. less	than 11	110	Br2
002-3	120	220	
NIO	20	65	
Ni203	30	90	Precipitated
Cu0 (H20)	68	3.95	Oxidized Metal
CuO	150	175	
00	120	155	by
Cu203	2.5	145	Precipitated by
MnO2(H2O)	15	190	0.821(
Mn02 Dry	67	265	Amerphous
MnzOc	240		anded during the war by
	This work was cor	tinued and exp	and developin; an ab

the Chemical Warfare Service with the object of developing an abscrbent 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%MnO₂). 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

4 4 1 X The second - And a second second state from a second state and the second 1 18 1 20 171 nonth for a de the second second N 10 1 and a set of the set of and the state of the second and the second interaction of the second the description of the second second second second second second second - Studies to be beneficial and and the second provide the second LE

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

5 5 A A

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 treatest importance are the factors influencing the distribution of temperature rise throut the catalyst tube. There is a temperature difference of only about 25-30 decrees 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 recomized 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, Jeldard and VanName, are as follows:

- 1. Removal of CO in multiple state apparatus.
- 2. Control of CO concentration.
- 3. Effect of Space velocity.
- 4. Heat conductivity of the fascous mixture.
- 5. Desi n cf Apparatus.
- 6. Effect of mesh of catalyst.

This work further shows that the temperature rise varys directly with the percent of CO in the as, in a riven 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 condentrations of little importance.

1. 10

6.

i. N.

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

 Reproducibility of results. Under identical conditions it is shown that a given sample of Ecocolite 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 rares. By temperature and by the space velocities.

4. Temperature control. Probably the most difficult, and certainly the most incortant 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. neverse, and the second constrained in the second states of the second s

4

i adal tey of the form of the Weinhord field by Sorried on this problem of the test of marker of weigh Freehold on Hellidia have been note to a compacible setentiation, these ord on this). second at visco on the second of the follow them and to the

tt is ghown that a stor cards of is walk's air solkbal and the

import and of analities there to a termination manifol to at iters? to decreas it which analis it excelsion at the st errotionals, and in which is approximate anisation of back of tables alone. White these is structure, make contributed or temps erroture they quarks and , it is product to be solutioned to ence the digromential condicate an effective is a structure of the structure is a second or the solution of the second or the structure and the solution of the solution of the digromential condicate a first a second or solution of the solution of the digromential condicate a first a second of the solution of the solution of the digroment of the solution of the solution of the solution of the solution of the digroment of the solution of the solution of the solution of the solution of the digroment of the solution of the solution

alget is selfadored eretter on costario and digon anneat co be enterine moreou of tanger tand of is the space mices interest of lenges rises aroticle from to for distinguis

and contention the react 1 contents are set of all of the set of t

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

7. *

¥. 89

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 overation, 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 cxygen content to be supplied and with the effect of those impurities most likely to be present in commercial ras.

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.

EXPERIMENT.L.

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

% concret 1* the date had the structure is the form % concret 1* the second second second second second second second % concret 1* the second second second second second second second % concret second second second second second second second second % concret second second second second second second second second % second second second second second second second second second % second second second second second second second second second % second second second second second second second second second % second second second second second second second second second % second second second second second second second second second % second second second second second second second second second % second second second second second second second second second % second second second second second second second second second % second second second second second second second second second % second second second second second second second second second % second % second second

and angles here a solution of a set of the second of the s

44、《理》、是《《法法》

(1) A set of the se

half an hour by means of an electrically stirring device.

0.

The gas was drawn thru the entire apparatus by suction, entering a sulphuric act, 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 *±*astened 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 $7\frac{1}{2}$ inches long, and $\frac{1}{2}$ 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 calvanometer pole, and the other wire thru a mercury connection thence to the second calvanometer pole.

The valuanometer was calibrated by plotting the readinvs 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 for suro-couple and any other one could be read off directly from the valuance ter scale. 1.1. The second of the second s the second s second secon second sec

(in such that the matrix of angle and the one and and and the represents, when we are the frequencies, and the subscreek the presentation and the target of the subscreek the presentation and the target of the subscreek the presentation and the target of the subscreek the target of target of the target of target

at the potential with a second of the second





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 Ig $O_{\rm b}$ method was adopted.

as he g. as b

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 gauge 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 gauge is placed between the last thermo-couple and the exit tube.

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 2.3 13.1 3.5 2.4 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. en and an and the content of the day and the advance in the day of the statement of the second stateme

(a) detrive the catelogy searing the fractory binders binders on an an an antiserie (share the second search with the standard share in artist in 100 bit as floored where of the thermalist. (Shar 1421) to take a search ray of a special botter the the last have been as a bit take a search ray of a special botter the last have been as a bit take a search ray of a special botter the last have been as a bit take a search ray of a special botter the last have been as a bit take as a search ray of a special botter the last have been as a bit take as a search ray of a special botter botter the last have been as a bit take as a search ray of a special botter botter the last have been as a bit take as a search ray of a special botter bott

There every a supervise of there is the even solver there is the solver is the solution of th

Toppingkine of training at the second fields

To de tradicio de la construcción de contente de 1993 entre de 1993 entr



the ef-fect of varying space velocity was undertaken.



Temperatures of thermostat 35 degrees. space velocity 1800. Content of CO in air-gas mixture 0.985. Oxidation of CO 90.2% arrangement of Catalyst: Pure catalyst thruout. Thermo-couple temperature difference in degree centigrade. No. 5 No 2 No. 3 No. 4 No. 1 1.6 0.4 1.9 8.3 3.6 Temperature of thermostat 40 degrees. space velocity 1800 Content of CO in air-gas mixture 0.96%. Oxidation CO 90.9% Arrangement of Catalyst as above. Thermo-couple temperature difference in degree centigrade. No. 5 No. 3 No. 4 No 2 No.1 0.0 0.9 1.5 8.7 3.8 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. 2 No. 3 No. 4 No. 5 No. 1 1.0 0.15 1.7 4.7 9.6 Temperature of thermostat 60 degrees. Space velocity 1800 Content of CO in air-zas mixture 0.96%. Gxidation 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 ...

NO . T	1.0.			
10.0	4.8	1,5	C.3	-0.1

The following chart shows these results graphically. It will be seen that the effect of temperatuge 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 effect of varying space velocity was undertaken.

Themperstikes of thermostat Sp degrees, upped a locatty Locat South 60 to collected . MR. Countries appendix at 00 to the suns .trouter for fater "iter total to deamer wars. o , oil a lot S . M L OH J . CH perop 20 matteries .got. Constitute analysis of 00 to shated There-couple termersters difference in derive continues. d . 01 10 2 10, 3 10, 6 Sin 6.0 910 B.I 018 9.0 Doal this for some .comes is to barry it is related as content of 60 in the sector of a billion builded of the internet of the sector . Minimizing parton dr secondriff instances & ofenoo-gener. 61.0 0.1 7.1 7.4 9.8 coul wire of the second of a terror of the metalenger Constantiation . See 9 multiple measure of 90 to treatmos . Bowness which of againer to the first soil make we first of and at 30 to matherize total news equipments and the state to these and 'wars wive of our standards first degree a part inter the were used at initial game, initial to fuely to edd

ea 1



maximum space velocity. It was block and fect 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. 5 No. 4 No. 3 No. 2 No. 1 -0.1 4.14 0.2 4.4 5.8 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. 3 No. 4 No. 5 No. 2 No. 1 1.3 2.6 5.2 7.2 9.5 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. 5 No. 1 No. 2 No. 3 No. 1 4.1 4.2 7.5 9.4 11.6 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. 3 No. 4 No. 5 No. 2 No. 1 1.7 5.2 3.3 8.3 13.8 These results are shown graphically on the following

These results are shown are proved 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;

11.

The affine a second of a second of the second of the second 2010000348 330° 100 ... 8 10 ... 8 10 ... 8 provide a state of the second state of the second state a set to set to set a set 3 . 51 21 -Sec. 2 9. 4 16.3 with allowing appendix to the first of the second and many of the share subject of the later of the state of the state of the A ATTACK AND A DESCRIPTION OF A Topped a constraint the constraint of a set of the statement of a set of the With half doubt doubt doubt The had the Sec. When the second second in the test of the second second the set of a weather that a constant stranger of the second PARAMETER AVERAGE TO THE PROPERTY OF a more service we have a service in the service of E. 3 al 19 and the set were the second to be an an addition of the second to be again the second the same to an extension of the state of the second s a service is a to the day but day up a top · 我们们不会说"啊!"你们们一定"家务"中国的的规模学习》 网络特别美国人的 化分离子的 化合金化合金化合金化 dealer want have a set 2 . . Sect. Test. and and the set of the water and the second of an analysis and a second and an experimental property of the second state of the second state of the second state of the

en de la seguradad de l'arte en restance en la serie de la seri La serie de la s

6.4.8


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 \$2.1% Arrangement of catalyst : Pure catalyst thruout. Thermo-couple temperature difference in degree centigrade. No. 5 No. 3 No. 4 No. 2 No. 1 0.1 0.4 0,95 2.9 14.6 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. 5 No. 3 No. 4 No. 1 No. 2 -0.2 0.3 0.6 1.7 16.8 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. 5 No. 3 No. 4 No. 2 No. 1 0.55 1.5 0.8 3.95 17.4 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. 2 No. 3 Ho. 4 No. 5 No.1 100 0 1.6 1.35 3.1 These results are represented graphically on the 20.0

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 cxides. A re-arrangement of the catalyst was next tried.

tonge Although as the second of a second as associated as a constraining (1.30 12 molifering distant and the contention of the second of the second analy provide the second of the regime in feature could grade. ê ., 29j 1 . . (E) . Duri estantes succes estado en setentetes de conservatere to see 00 to apply the lithest states of ments at 00 ministration survey be issuinced to included the septerificed measure of contrastic encountered at the sector it was -5 .01. 5 .eff 1 the destriction of the subsect on the source and a state source contests of 00 to all all other bisseries and one factors of 00 the - more an invitates to idenogramina . el retros serves es estraçon da conserve conserve de adares estas 5 . S. 1 1.0K 8.01 8.198 1 1.31 A. I. Alert Sint course recorded and the second second an example of the establishing content of 60 to available have a statute to 20 million of 60 million the second second and the second second second second from the second se 15 54 and no elleveld on theproperty of ellevel and as as reactive processing a star \$5 assumes. In other processing as

Anter share on canceletter of the discount share of the canceletter.
 Anter share on canceletter of the canceletter of the canceletter share of the canceletter.





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

Continued on following page

+100

and have to be the state of the state of the test of the state of the เป็นของที่เป็นสำคัญ ของสุรักร์ การเองชอง เป็นไปสำครรรมสาย สำคัญ เรื่องชื่อเรื่องสุรักร์ เป็นของที่เป็นสำคัญ เป็นสาย เป็นสาย เป็นไปสาย เป็นไปสาย เป็นสาย เป็นเป็นสาย เป็นสาย เป็นสาย เป็นสาย เป็นสาย เป็น เป็นสาย เป็นสาย เป็นสาย เป็นสาย เป็นไปสาย เป็นไปสาย เป็นไปสาย เป็นสาย เป็นไปสาย เป็นไปสาย เป็นไปสาย เป็นสาย สาย เป็นสาย เป็นสา A solid the second s active said Content vie to in each anter beiter bereichten and weite vie to be the 190 aber ingen beiden in de Bourdarie einderstenet effection einen . . . 1 1. 1.5 E.E 2 . 0 ระกังกันนี้สาวการของการที่ไป ของสุดการไม่ไป การกำรงการการ เริ่มการการที่ไ . setting at he has a 80.03 E O.1 8.1 a. 1 Comparents of the manual to degree and weiters in and tenas 80 drifetiko velleren en bestelm an erte ut 400 to Japinso "identifies with as easter and stand of any of the stand . setunica OS to bae 35 1 . 51 TOUGH SALENDER ON SO TRACKS AND

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.

 At end of 25 minutes, c. 3
 No. 4
 No. 5

 No. 1
 No. 2
 Nc. 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 <u>tube content</u> per hour of time, while the latter represents the space velocity as liters of gas per <u>liter</u> of <u>catalyst</u> per hour of time.

14.

lepitoratory of therebet * on Astrony there extensis 200 Confere of 00 in strend marcare 1.20% Chitation of 03 68.0% Arragement of estable11 in above

Thermerstephie temperatives in the antistude continues in a second state in a second

The provise are chosen propriority on the Millerton parts, it is posentin in the worklast require fource filteriants (194 time, at the and of it comptee the existing being only block a deterministion of the existing of the est of the which five who are not exceed.

It was devided for vary the phonol first of formal cotalyst threathy antelyst two in an athened to d'arreland the temperature are norma arealy and also of frontile like tathers of the moceausy for the assoirst to give constant realist for all as noticed in the transit of the realist

blie points of the event that the even velocity of given in the reveal designated. Self and as N... The first represents the apage velocity as litters of gas par litter of <u>the called</u> concontrol time. chain, the light self encored and the apage of the reveal of the self of <u>constructed</u> per nous of the reveal of the self of <u>constructed</u> per nous of the.





Temperature of thermostat 50 degrees. Space velocity 3600 Content of CO in air-gas mixture 0.63% Oxidation of CO 90% 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 -0.8 0.6 1.6 4.2 1.8 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. 3 No. 4 No. 5 No. 2 No. 1 2.2 1.75 0.8 3.2 3.8 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. 10.3 No.4 No. 5 Nc. 2 No. 1 0,9 1.75 3.2 2.1 3.8 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. 2 No. 3 No. 4 No. 5 110. 1 0.4 4.0 1.4 7.2 5.8 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. 5 No. 4 No. 1 No. 2 No. 3 1.75 3.0 4.0 8.6 5.8 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. 4 No. 5 No. 3 No. 2 No. 1 1.0 2.6 5.4 4.4 8.8 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 2.6 1.2 5.6 These results are shown graphically on the following 8.8 5.2

e 🛞

16.

4.45

These results are shown of the above constancy 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 of CO concentrature rise for gas of 0.86% than for that of gas of reaximum 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.







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 0.2 4.1 2.6 6.6 7.4 At end cf 15 minute run (other conditions same) No. 1 No. 2 No. 3 No. 4 No. 5 7.8 5.8 3.4 0.9 3.2 At end of 20 minute run (other conditions same) No. 5 No. 1 No. 2 No. 3 No. 4 1= 6 0.9 3.2 7.9 7.8 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) Nc. 1 No. 2 No. 3 Nc. 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.





Continued on following page.



Tempera	ture of thrm	nostat 50 de	egrees. Space	e velocity	3600
Content	of CO in ai	.r-gas mixtu	are 0.86% Cx:	idation of	CO 99.6%
Arrangen	ment of cata	lyst; First	t couple three	ee parts ca	talyst 1 part
brick.	Second and	third coupl	les 1 part ca	atalyst to	lpart brick.
Remainir	ng two all o	atalyst.			
Thermo-couple temperature difference in degrees centigrade.					
At end o	of 10 minute	s run.			
No. 1	No. 2	No. 3	No. 4	No. 5	
11.1	10.2	4.8	3.8	802	
At end of	20 minutes	run(other	conditions s	same as abo	ve)
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 s	same)	
No. 1	Nc. 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 s	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)

Noll	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.

110. 1	10. 2	110.3	Nc. 4	llc. 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	Nc. 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.

(a) an an instance of the matrix of the matrix of the second constance. The second constance of the

and a second s

 1.1
 1.1
 1.4
 1.4

 1.1
 1.4
 1.4
 1.4

 1.4
 1.4
 1.4
 1.4

 1.4
 1.4
 1.4
 1.4

 1.4
 1.4
 1.4
 1.4

 1.4
 1.4
 1.4
 1.4

 1.4
 1.4
 1.4
 1.4

 1.4
 1.4
 1.4
 1.4

 1.4
 1.4
 1.4
 1.4

 1.4
 1.4
 1.4
 1.4

spect of the set of the set

the provide the second of the second of the second se

Conversion of Charles in the receiption of the second

made in the state of the second of the second of the second 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.



20.	
Sector Soldstand	pace velocity 3600.
Temperature of thermostat bu degrees. Sp	$\mathbf{r}_{idation of CO 98.9\%}$
Content of CC in air-gas mixture 1.22%	atte actalyst to 1 mart
Arrangement of catalyst: First couple 3	parts catalyst to I part
brick. Second, 2 catalyst to 1 brick. Th	hird, 2 catalyst to 1 blick.
Remaining two all catalyst.	
Thermo-couple temperature difference in	degrees centigrade.
At end of 5 minutes run.	
Nc. 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 conditi	ons same as above)
No. 1 No. 2 No. 3 No. 4	Nc. 5
11.1 10.2 5.8 5.0	#8. B
At end of 15 minutes run (other condit	ions same)
No. 1 No. 2 No. 3 No. 4	po. 5
a 10.8 5.8 5.0	3.0
at and of 20 minutes run (other condit	ions same)
No. 2 No. 2 No. 3 No. 4	10.5
0 A 1811 5.6 5.8	2.6
At and of 25 minutes run (other condit	cions same)
No. 2 No. 2 No. 3 No.	4 No. 5
NO. 1 121 5.7 5.6	2.8
the set of 30 minutes run (other condi-	tions same)
At ena of so minated that No. 3 No.	4 No. 5
No. 1 10. 2 10. 5.8 5.7	2.8
8.0 12.0 0.0	graphically on the following

00

These results are shown graphically on the forfering page. By arranging the catalyst as above a large propertion 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.







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 $\frac{1}{2}$ 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 abo	ve
No. 1	No. 2	No. 3	110.4	No. 5	
6.9	3.2	7.1	5.8	2.2	
At end of	50 minutes	run (other	conditions	same)	
IJo. l	No. 2	No. 3	No. 4	No. 5	
6.8	3.0	7.1	0.6	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 99.35 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.

··· 21.· ··

2 1. C.A. the art sufficience antit to this part a prime a prime and a prime in a second a prime when a prime of the sufficiency of the sufficience of the sufficiency of the s 0. 0



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 cf 20 minutes run.

No. 3 No. 1 lio. 2 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 2.0 2.4 At end of 30 minutes run (other conditions same) 110. 2 No. 1 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. 2 No. 3 No. 1 No. 4 No. 5 2.8 2.4 6.9 2.8 3.0

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 ε^{-1} 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.

true Lint texterne strug & slares staristes to transport the off same a soft This data is shown are abready on the following fight. the last four encodes, but the first gougle remains somehat but



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 $\frac{1}{4}$ 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.

23.

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. 3 No. 4 No. 1 No. 2 No. 5 3.2 4.2 3.7 5.4 1.4 At end of 30 minutes run (other conditions same) No. 3 No. 4 No. 5 No. 1 110. 2 4.2 2.2 3.9 3.4 6.0 At end of 35 minutes run (other conditions same) No. 5 No. 3 No. 4 No. 2 No. 1 2.0 5.8 3.4 3.8 3.6 At end of 40 minutes run (other conditions same) No. 2 No. 3 No. 4 No. 5 No. 1 2.2 4.2 3.3 3.1 5.8

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.





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. 2 No. 3 No. 4 No. 5 No. 1 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) 10. 2 No. 3 No. 5 No. 1 No. 4 3.6 3.7 4.8 2.6 2.4 At end of 35 minutes run (other conditions same) No. 2 No. 3 No. 4 No. 1 No. 5 3.6 3.4 4.6 2.4 2.1 At end of 40 minutes run (other conditions same) Nc. 2 No. 3 No. 4 No. 1 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.

responsants of there are a derived a set of the state of the set of the set of the state of the

se sur re recordente de constant administration de contract est

	49. D	6 4612	5 :91	S 4-72	rio, 1
		2,5	H _S A	₹.5,	1 . h
v.ojo.n	64. 2003		anutal usa	estudiu ga	re bige ga
	d , gill	A 108			
	A. F		0.4		
		enci stibilog	nedito) aga		
	S. 497		8 .01	S07	10, 1
	$\theta_{12} \theta_{1}$			5,7	3.0
	(ទេសក្រខ,	West there	tenalo), noa	sociation an	
	4 + 94	N			10, 2
	Ę.5	2.3	à.,b	A.E.	
		alita refit factor			
	d,	No. 4	80, ,8	8 .01	10, 2
	1.3	S. 8.	â _n e		8,8

Ττο τουποίη να ποσου σοτορηζατο της εξουπο τολλογικας το του στη έξετο του το ποριτοτη το ποσου το ποριο του του το ποριο το ποριο τηθει το το ποριο το τουποίου το ποριο του το ποριο το ποριο το ποριο τηθει το το ποριο το τουποίου το ποριο του το ποριο το ποριο το ποριο τηθει το το ποριο το ποριο τουποίο το ποριο το ποριο το ποριο τηθει το το ποριο τουποίου το ποριο του το ποριο το ποριο το ποριο τηθει το το ποριο του τουποίου το ποριο του το ποριο το ποριο το το ποριο το ποριο του ποριο του το ποριο το ποριο το ποριο το το ποριο το ποριο του ποριο του το ποριο το ποριο το ποριο το το ποριο το ποριο του ποριο του το ποριο το ποριο το ποριο το ποριο το ποριο του του το ποριο το ποριο το ποριο το ποριο το το ποριο το ποριο του ποριο του το ποριο τ



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 CC 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 3.7 3.4 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 cxidation 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.





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 mariable. 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 Ho. 5 4.4 5.9 8.2 4.3 4.4 CO content of tas 1.31; Oxidation of CO 98.95 Other cond. same. No. 1 No. 2 No. 3 No. 4 No. 5 3.3 4.6 5.4 5.2 4.4 CO content of gas 0.96% Oxidation 99.1% Other conditions same. No. 2 No. 3 No. 4 No. 5 No. 1 4.8 2.6 2.2 4.2 3.6

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 oridation 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.







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-ccuple temperature difference in degrees centigrade. Space velocity 2000.

1VO. 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	110.4	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.





doubeled. The cxidation is slightly less for the higher space velocities.

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



DISCUSSION.

In a study of a given problem in which the result scught 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.

28. . +

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 cO 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 physe 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

all manager and a second se The second se

And Constant of the second seco

- and the second state of th

a La na terre de la companya de la compa

And the second s

A MALE SALE SALE AND A SALE AND A

a the second of the second of

High a strange war in the strange w

was shifted from the first to the second couple; is a result it was thought feasible to have a dilute mixture at the first part of the tube and propressively increase it cward the end, in an attempt to shift a part of the exidation toward the far end of the tube. Such an arrangement still gave the major part of exidation 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 arcund 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 ccuple 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 satisfact ry 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 l. tc l. 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 cxidize this increase cf catalyst in number 3. would be necessary. The results show, however, that this ratio around number 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.

31.

e 14 14



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

32. "

19.14

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 imp proved upon, because sc cften 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 ware 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

statistics of a state of the second state



catalyst, we failed to completely clean cut the calcium chloride and phesphorus 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.

33.

¥ 1900

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-H₂ mixtures require much higher temperatures for 0xidation 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 * 0

32 0

vir senter 11 sin en altre en el en en el el senter el senter el senter el senter el sen el sen el sen el sent 1 de electric 11 sin el senter 1860 de senter el senter el senter el sel senter el 1860 de senter el sen

where and the series of the second second and a second
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 icewater tower. The result was instantaneous. The galvanometer deflection immediately dropped considerable, and an analysis of a sample showed 4 that the oxidation had failen 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.

54.

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. A statistic second se

-65 (1) en des part dates at the second at the second at the state of the second at the state of the second at the

- 47 14 1 F. M.

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

~ ~

25.

3.

3. Water vapor poisons the catalyst and necessitates a higher temperature of the thermostat for complete oxidation, withcut necessitating a re-arrangement of the catalyst in order to maintain an even distribution of temperature rise within the catalyst tube.

FINIS.

and a state of the second basis of the second s and second s

and the second second second and the second second

1111

.....

2 0

and and a





WX 001 556 009