DEVELOPING A COMMERCIAL GAS CARBURIZING UNIT USING KANSAS NATURAL GAS AS THE CARBURIZING MEDIA

by

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INTRODUCTION

The fundamental underlying idea of gas carburizing dates back to the middle of the 19th century. In its early stages only experiments along lines of scientific theory were conducted. It is believed that the birth of gas carburizing probably occurred quite by accident as have many modern day inventions.

Early heat treaters were continually troubled with the decarburizing of heat treated parts. In an attempt to prevent decarburizing, coal gas was introduced into a preheated chamber used for heat treating. Coal gas at low temperatures, 1400 degrees F., prevented decarburizing but at higher temperatures, 1600 degrees F., it caused a carbon rich case to appear on the heat treated part. Proper heat treating caused the case to become hard and wear-resistant.

The first experiment (23) in gas carburizing research was carried on in a vertical stationary type of furnace with natural or manufactured gas and air as the carburizing media (22), but was discontinued due to difficulties encountered with heavy sooting. This heavy soot formation precipitated the development of the rotary type gas carburizing furnace. The rolling effect of the rotary type furnace caused the soot to flake off of the carburized parts. One disadvantage of the rotary furnace was that only strong, non-precision parts could be carburized because of the continual hammering created by the rolling parts.

The first important publication on gas carburizing was written by an Italian, Federico Giolitti, early in the 20th century in his book, "Cementation of Iron and Steel" (9). This book was published in English in the United States in 1915. Giolitti clarified many vague ideas and conflicting opinions by conducting numerous experiments in the carburizing field.

Developing of gas carburizing on a commercial scale in the United States began with the granting of the first patent (23) for a rotary type gas carburizer in 1906. Continuous gas carburizing came into being in 1913 and was accomplished by using a spiral ribbed retort in a rotary type furnace. Vertical type gas carburizing furnaces were reintroduced in 1924 and by 1929 had gained considerable popularity because of the demand for a furnace capable of carburizing large parts in greater quantity.

Eliminating heavy soot formations in gas carburizing furnaces by the use of diluting gases (carrier gases) of steam, charcoal producer gas, nitrogen and air was undertaken in 1925. The carbon content was controlled by varying the ratio of diluting gas and carburizing gas. This arrangement gave excellent results. These carrier gases are produced in outside generators and then mixed with the enriching hydrocarbon gases before it enters the furnace.

Early gas generators (23) used peat moss and charcoal because of their sulphur-free composition. The city gas was passed through a scrubber and then through a gasoline bath where it became rich in hydrocarbons before entering the furnace retort.

Despite many new developments in the modern metallurgical field, there has not yet been developed a satisfactory shop size carburizing furnace employing natural gas. Therefore, in this thesis the author is concerned with the design and development of a commercial shop size gas carburizing furnace which utilizes Kansas natural gas as the carburizing media and air as a diluting gas.

Part of this thesis is dedicated also to the development of an internal generator for this furnace. This generator is in the form of a tube filled with charcoal, utilizing the heat of the furnace retort in developing a carburizing atmosphere from the air and gas mixture passing through the heated charcoal. The decision to place this charcoal tube in the carburizing furnace was due to the proximity of the temperatures employed in commercial gas carburizing with those of special atmosphere generators. This generator also decreased the complexity of gas carburizing units.

REVIEW OF LITERATURE

Basic concepts of carburizing were thoroughly discussed by Floyd E. Harris in "The Metals Handbook" (13). But it was of particular interest to read an article in Metals Progress describing three different theories pertaining to the concentration of carbon in a carburized case. Harris (12), McQuaid (18), and the author, Breithart (2), explain their theories. Harris believed that the carbon content called for by the Acm line in the iron carbon diagram was closely approached when proper carburizing conditions were used and that excessive carbon build up above saturation was abnormal. McQuaid contended that extremely high carbon contents were achieved as the results of normal phenomenon. Breithart went to greater lengths and combined his own theory with that of Harris and McQuaid in saying

> The maximum surface carbon content in carburized cases depends on the microstructure of the steel during the process of carburization. Excessive carbon contents will be obtained in the case when steel contains "free" carbides of carbide nuclei during carburization. Carbon contents called for by the Acm line modified according to alloy content will be obtained when the steel is homogeneous austenite during carburization.

Dow (7) discussed all the important chemical reactions, carburizing gases, equilibrium constants, gas concentrations, diluting gases and the proper procedure of furnace operation in his article entitled, "Gas Carburizing". Similar articles by the same title were written by Kopecki (15) and Leland (16). Kopecki explained how clean carburizing could be achieved by using regulated amounts of gas during the carburizing cycle and by introducing natural gas into the cooling furnace. Leland was also concerned with the fundamental of gas carburizing and furnace operation. Strangely enough, Leland's summarizations were well suited to the operation and functions of the carburizing furnace used in this research.

The effects of temperature, rate of flows, and time using carbon monoxide was investigated by Bramley and associates (1). They also investigated the diffusion of carbon in steel.

Cowan (6) completed successful carburizing with natural gas, propane, butane, and acetylene in combination with flue gas. Carburizing was accomplished through the reaction of the flue gas and the soot which formed carbon monoxide. This led to the development of continuous carburizing in three distinct zones. Heavy concentrations of gas produced soot in the first zone, carburizing occurred in the second zone, and in the third zone diffusion was completed.

Mattocks (17) discussed the appearance of the flames produced by the burning of exhaust gas of a furnace and illustrated the relation of composition of the gas to the color of the various zones in the flame. He also discussed the dissociation of carbon dioxide into carbon monoxide and oxygen and the dissociation of water vapor into hydrogen and oxygen.

A discussion of furnace atmospheres was presented by the American Society for Metals (5). Various methods of clean hardening are discussed by Harris (11) along with the equilibrium constants, moisture content, oxidizing tendencies desired to produce clean hardening. Comparison is also made of the atmosphere required for gas carburizing and clean hardening.

Using spent gases as carrier gases was accomplished by Holcraft Company (14). This eliminated the need for an outside generator. The spent gas was recharged with fresh hydro-carbons before reentering the carburizing furnace.

Stansel (21) developed equilibrium curves for various gases composing a carburizing atmosphere. These curves are based on equilibrium with carbon saturated austenite at various temperatures. Many phases of gas carburizing were reviewed and discussed in the Carburizing Symposium of the American Society for Metals. (4).

GAS CARBURIZING

In gas carburizing the carbon is transferred to the steel through gaseous hydrocarbons or carbon monoxide. The actual carburizing (19) is dependent upon two basic mechanisms: one pertains to the source supplying the carbon to

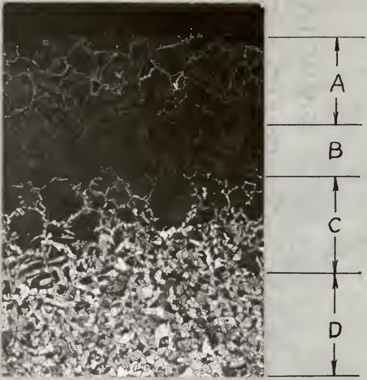


Fig. 1. The zones in a carburized specimen.

A. Hypereutectoid

B. Eutectoid

C. Hypoeutectoid

D. Core

the steel surface, the other pertains to the diffusion of carbon into the steel.

The diffusion of carbon in steel readily takes place when the steel is in the austenitic state; that is, when the iron is in the gamma allotropic form. Iron in this form encourages the diffusion of carbon into steel because of gamma iron's ability to absorb up to 2 per cent carbon. Most commercial carburizing takes place at a temperature of approximately 1700 degrees F. At this temperature gamma iron is stable.

The diffusion of carbon (19) proceeds from a higher concentration to a lower concentration. The higher concentration comes from the carburizing media. The gradiation of carbon content from the high carbon surface to the low carbon core is known as the carbon gradient (Fig. 1) while the difference in carbon content of the outer surface and core is called the "carbon spread".

The rate of diffusion of carbon into steel is dependent upon the temperature and the carbon concentration of the carburizing atmosphere. At higher temperatures, the rate of diffusion increases but at a given temperature the case depth is dependent upon the length of time involved in the carburizing run. Case depth can be calculated by multiplying the square root of the carburizing time (in hours) by a constant for the given temperature. These constants are: 0.018 for 1600 degrees F.; 0.021 for 1650 degrees F.; 0.025 for 1700 degrees F.

In the early stages of each carburizing run the carbon demand of the steel is relatively great and an atmosphere containing a high concentration of carbon is required. To minimize (10) the length of time necessary in each carburizing run it is best to equalize the carbon concentration with that of the solubility of carbon in austenite since the diffusion rate of carbon in austenite increases proportionately with surface carbon concentration.

The transfer of carbon to the steel surface occurs through a chemical reaction which, in the case of gas carburizing, involves a methane and carbon monoxide reaction. They are:

$$CH_4 \rightleftarrows (C) + 2H_2$$
$$2CO \rightleftarrows (C) + CO_2$$

The carbon available in CO and CH_4 is based on the assumption that the reactions proceed until they are in equilibrium with the saturated austenite at the steel surface. It has been experimentally proven (19), however, that the concentration of CH_4 necessary to be in equilibrium with saturated austenite must be many times that of the calculated value. The speed at which some reactions move toward completion has proved that many reactions are faster than others and that the carbon monoxide brings the carburizing atmosphere almost into equilibrium with saturated austenite in a very short time.

Since the gas carburizing atmosphere is created partially by the combustion of hydrocarbon gases, the resulting reactions produce water vapor, carbon monoxide and carbon dioxide along with methane and hydrogen. The methane and carbon monoxide are desirable but the remaining gases are undesirable as indicated in reactions 1, 2, 3, and 4. The principle of equilibrium stems from these mixtures. The two main equilibrium ratios are H_2O/H_2 and CO_2/CO. It is always desirable to hold down the concentration of H_2O and CO_2 and to increase the concentration of H_2 and CO. A definite relationship (10) exists between the H_2/H_2O ratio and CO/CO_2 ratio of furnace atmospheres in accordance with the water gas equation

$$CO + H_2O \rightleftarrows CO_2 + H_2$$

The water gas constant is expressed as

$$K = \frac{(CO) \qquad\qquad (H_2O)}{(CO_2) \qquad\qquad (H_2)}$$

From this equilibrium relation shown, it is clear that a reduction in the water-hydrogen ratio must be accompanied by an increased carbon monoxide-carbon dioxide ratio. Therefore, a low moisture content would indicate a low carbon dioxide content.

The effects of gaseous mixtures on steel at various temperatures are shown in Plate I and illustrated by reactions 1, 2, 3, and 4.

1. $Fe + H_2O \rightleftharpoons FeO + H_2$ oxidizing, scaling
2. $Fe + CO_2 \rightleftharpoons FeO + CO$ oxidizing, scaling
3. $CO + H_2O \rightleftharpoons CO_2 + H_2$ decarburizing, oxidizing
4. $3Fe + CH_4 \rightleftharpoons Fe_3C + 2H_2$ carburizing or decarburizing

Gas carburizing furnaces utilize a "carrier gas" the most common of which is produced by introducing a stream of air into a heated chamber of charcoal. The reactions involved cause the carbon dioxide to convert partially to carbon monoxide and the water to hydrogen and carbon monoxide.

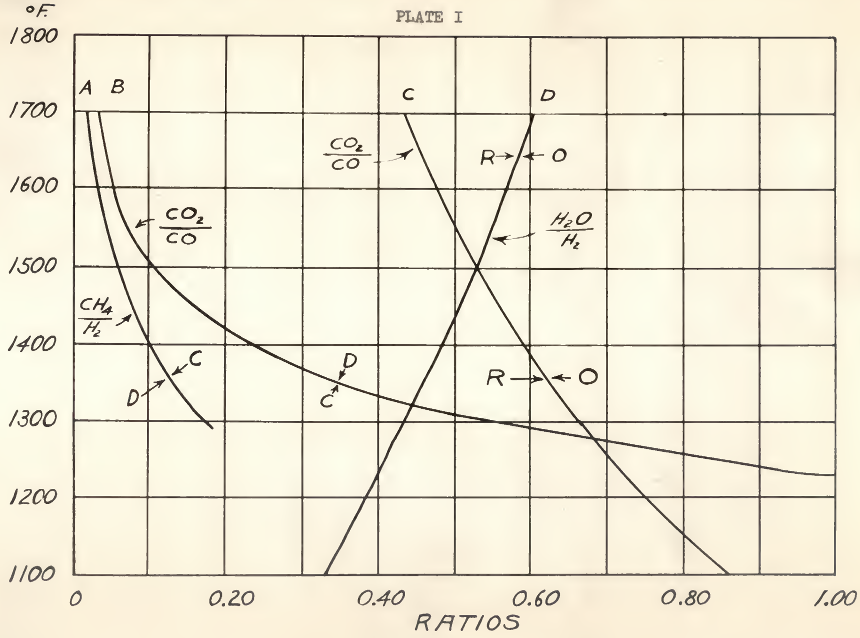
Gas carburizing atmospheres that utilize natural gas also use a diluting gas. The purpose of this diluting gas is to prevent the heavy sooting that takes place when just natural gas is introduced into a carburizing furnace. The diluting gas also serves as a means of circulating the atmosphere and exerting pressure to prevent the infiltration of air into the furnace. For all practical commercial purposes gas carburizing is never done at a temperature above 1700 degrees F. since with the increase in temperature there is an increase in grain size, exaggerated distortion and accelerated deterioration on the furnace retort.

EXPLANATION OF PLATE I

Stansel's curves which are based on equilibrium with austenite saturated with carbon at any particular temperature.

D	Decarburizing area
C	Carburizing area
R	Reducing area
O	Oxidizing area

PLATE I


°F.
1800
1700
1600
1500
1400
1300
1200
1100
0
0.20
0.40
0.60
0.80
1.00
RATIOS
A
B
C
D
$\frac{CO_2}{CO}$
$\frac{CO_2}{CO}$
$\frac{CH_4}{H_2}$
$\frac{H_2O}{H_2}$
R→ ←O
R→ ←O
C
D
D
C

EQUIPMENT AND ITS ENGINEERING PROBLEMS

The furnace, as shown in Plates II, III, IV, and V, consisted of a lid lined with a refractory material, a furnace retort which was supported inside heating coils, a supporting base of fire brick covered with asbestos, a david used to lower or raise the lid, and a control board with instruments for controlling temperature, gas flows, and time of furnace operation.

The furnace retort was an all-welded unit of 3/32 inch thick inconel metal; it was 21 inches long and 10 inches in diameter. A sand seal (Plate IV) one inch wide and two inches deep was welded to the top of the retort. Inconel is composed of 80 per cent Ni, 14 per cent Cr, and 6 per cent Fe; it has high strength, high resistance to corrosion and oxidation at high temperature.

The furnace lid was constructed of 3/32 inch thick steel. Through the top of the lid passed four inconel tubes. The largest of these was 2 inches in diameter and extended 17 inches below the lid so as to obtain the full benefit of the heated retort. This large tube (carbon tube) through which the carburizing gas and diluting gas passed, was filled with charcoal for part of the runs and left empty in others. The remaining three tubes were made out of standard one-half inch inconel pipe. The first small tube was used as an exhaust outlet, the second as a protective housing for the temperature controlling thermocouple wires, and the third as a means of introducing and extracting samples. A 1700 RPM motor was mounted on the lid to drive a circulating fan inside of the furnace.

While making carburizing runs on light loads of 1/18 inches steel sheet, it was discovered that the carburized cases produced were uneven in depth and carbon spread. The first assumption was that the fan was not circulating the atmosphere sufficiently. In order to improve the circulating effect of the fan, a sleeve shield was welded around the fan on the bottom of the lid. This shield forced the air down through the center of the furnace, to the bottom of the furnace, up the sides of the furnace and back down through the sleeve.

The next carburizing run showed that the carburized cases produced at various points in the furnace still varied considerably. It was then thought that the trouble was in the rate of circulation of the atmosphere. In order to speed up the circulation, a large motor of 3000 RPM was mounted in place of the 1700 RPM motor. But, after another carburizing run, the cases produced were still not uniform in depth. No better case was produced by changing the direction of rotation of the fan.

It was noted that the portion of the sheet steel near the bottom of the furnace developed a utectoid case while the case produced near the top of the furnace was all hypoeutectoid. This discovery led to the belief that the temperature in the furnace was uneven. Then, with the aid of a potentiometer and two thermocouples, the temperature at the top and bottom of the furnace was measured.

The temperature readings (Table 1) show that the difference in temperature was greater than 120 degrees F. This difference in temperature would account easily for the uneven case depth. The method employed to correct the difference in temperature was simple. Since the temperature at the bottom thermocouple was 120 degrees F. hotter than the top thermocouple, it was concluded that the lid was conducting a large amount of the heat away from the furnace. In order to correct this fault, a thicker layer of refractory material was cemented to the inside of the lid (Plate V). After this correction, the following thermocouple readings showed that there was only a difference of about 20 degrees F. (Table 1) between the two thermocouples and the next carburizing run produced a uniform case throughout.

Bronze bearings were first used with the fan shaft and when carburizing at a temperature of 1650 degrees F. the bearings held up fairly well but when the temperature was raised to 1700 degrees F. the bearings failed and replacement bearings lasted only a short time. The main cause of the bearing failure was the whipping effect of the fan shaft at the higher temperature. The only satisfactory way to correct the difficulty was to re-design the motor mount, fan shaft, and to use different bearings and bearing housing.

Increasing the rigidity of the motor mount was accomplished by supporting the bearings and housing on one 1/2 inch steel plate and the motor on another. This bearing plate was placed on supporting angle irons that were secured to the bearing plate. The bronze sleeve bearings were replaced by ball bearings. To increase the strength of the fan shaft, a larger shaft of 5/8 inch diameter was used. The final design is shown in Plate V.

One of the first problems encountered during the research was the varying moisture content of the furnace exhaust gases. These differences were encountered while using the same flows. The gas and air entering the furnace had to be dry in order to show that any difference in dew point could be attributed to the gas reactions in the furnace. Dew point readings taken of the gas showed that it was dry. In order to dry the air, a water trap and a drying chamber containing silica jel was also installed on the high side of the air line. This combination kept the air dry unless the silica jel became saturated. When this happened, the silica jel was was placed in a drying furnace for three hours or overnight and allowed to dry at approximately 300 degrees F.

In order to allow the charcoal in the tube to come up to the carburizing temperature and thus be effective in converting water vapor to hydrogen and carbon monoxide, the furnace was turned on five hours before the first run was started. A timer was installed on the control board so that the "on" and "off" cycle of the furnace was all automatic. The furnace was always on from 3 A. M. to 5 P. M. except on Sundays and holidays.

When carburizing at 1650 degrees F., both fine (¼ inch maximum) and coarse (½ inch maximum) charcoal particles were used and it was found that the increased surface provided by the finer particles caused greater lowering of the dew point. The finer charcoal, however, caused some trouble due to clogging as a result of soot formation in the tube. Using fine charcoal particles was no longer necessary when the carburizing temperature was raised to 1700 degrees F.

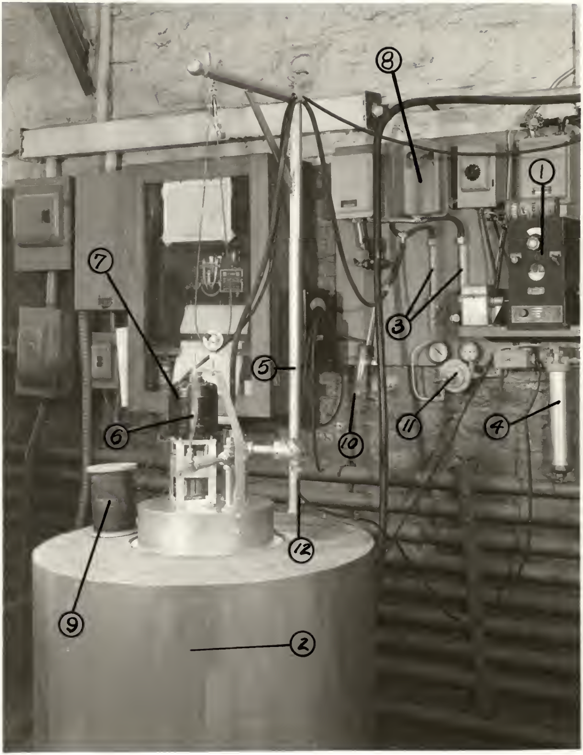
Checking the ability of the coarse charcoal particles to remove moisture was accomplished at 1700 degrees F. by allowing the gas and air to bubble through a test tube of water before entering the furnace with flows of 3000 cc of gas and 2000 cc of air; dew point readings taken of the exhaust gases of the furnace averated 20 degrees C. which is exceptionally dry. Dew point reading of the gas and air as it left the bubbler tube was a plus 20 degrees C.; this was an indication of high moisture content. But, as the gas and air entered the bubbler tube, the dew point was a minus 30 degrees C. (or lower). Dew point readings taken without the air flowing in the bubbler tube were as low as minus 30 degrees C. From this information, the importance of the charcoal tube in removing moisture can be appreciated easily.

EXPLANATION OF PLATE II

Gas carburizing furnace and control board in background.

1. Temperature controller
2. Furnace
3. Flow meters
4. Silica jel tube
5. David
6. Burning exhaust gases
7. Fan motor
8. Time controller
9. Cooling furnace
10. Dew point determinator
11. High and low side air pressure gauges
12. Thermocouple leads

PLATE II

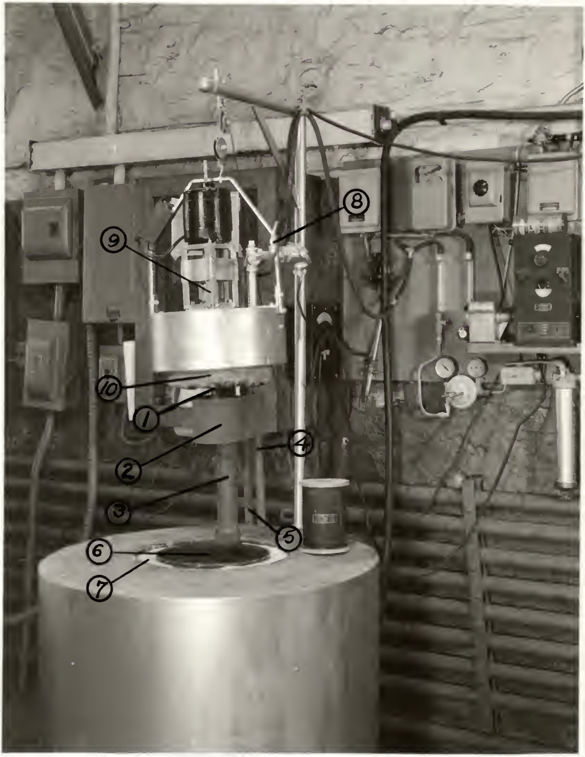


EXPLANATION OF PLATE III

Furnace lid lifted off of furnace retort so as to observe the actual arrangement of tubes.

1. Fan shaft
2. Fan sleeve
3. Charcoal tube
4. Thermocouple tube
5. Auxillary tube
6. Furnace retort
7. Sand seal
8. Sample and exhaust tube
9. Motor mount and bearing housing
10. Refractory material in lid

PLATE III



EXPLANATION OF PLATE IV

The principal parts of the gas carburizing furnace.

1. Outlet tube
2. Intake tubes (gas and air)
3. Motor mounts
4. Cooling fan
5. Thermocouple wires
6. Sample tube
7. Charcoal tube
8. Refractory material
9. Furnace lid
10. Sand seal
11. Circulating fan
12. Thermocouple tube
13. Furnace retort
14. Intake gas outlet (retort)
15. Outlet gas intake (retort)

PLATE IV

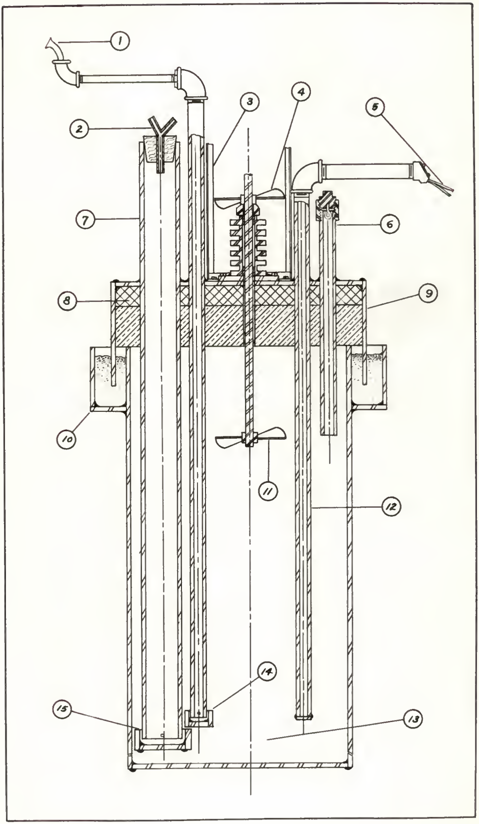


Fig. 2.

A. The case produced on a steel sheet in the top of the furnace.

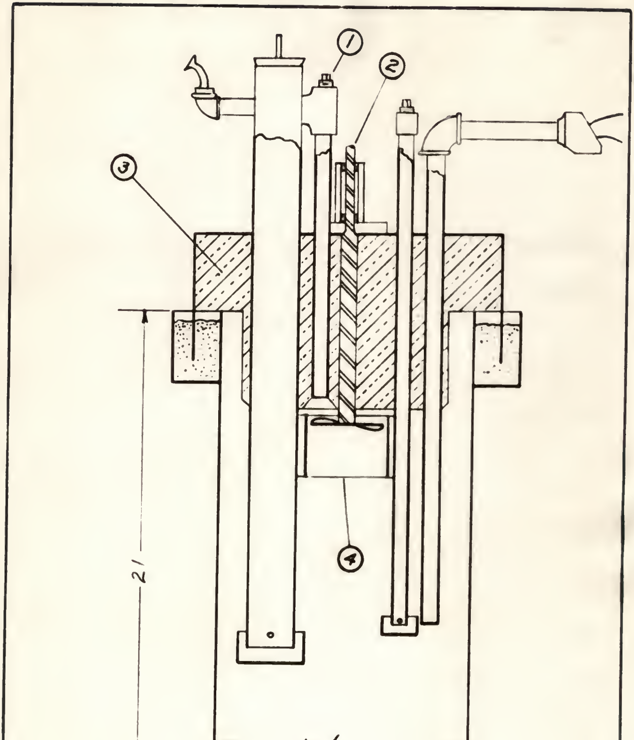
B. The case produced on the same sheet in the bottom of the furnace.

EXPLANATION OF PLATE V

Engineering improvements cause new furnace design.

1. Exhaust outlet and sample tube combined
2. New motor mount with over-size shaft on ball bearings
3. Increased thickness of refractory material
4. Sleeve over circulating fan

PLATE V



EXPERIMENTAL PROCEDURE

To allow time for the furnace to come up to the required temperature by 8:00 A. M., a time controller was installed and set to put the furnace into operation at 3:00 A. M. This time controller also turned the furnace off at 5:00 P. M.

The possibility (20) of explosion was avoided by making sure that the temperature of the furnace was above 1400 degrees F. before allowing the desired flows of gas and air to enter the retort. Since 1400 degrees F. is the kindling temperature of most gases, any mixture introduced will burn upon entering the furnace at the usual carburizing temperatures. The general danger of explosion occurs when a quantity of an explosive mixture is heated to the kindling temperature. To alleviate this danger, the furnace was purged with natural gas before starting and shutting down.

After a one hour duration of each carburizing run, the dew point readings were made as well as an analysis of the exhaust gases. Gas analysis was discontinued for awhile because of a defective catalytic tube.

The steel used for carburizing was cold finished, S.A.E. 1117 steel, a carburizing grade of free machining steel containing approximately 17 per cent carbon. These samples were 3/8 inch in diameter and approximately 1 3/4 inches long.

Three samples were stamped with a number which designated a particular run, each run indicating particular air and gas flows. Each of the three samples were stamped with one of the letters: A, B, or C. The letter A meant the sample was carburized for one hour, B for two hours, and C for three hours. The samples were fastened to a wire marked with one, two, and three notches to indicate which lettered sample was fastened to the wire.

In the earlier runs, it was noticed that samples which were corroded had an uneven case depth. This necessitated cleaning the samples before subjecting them to the carburizing atmosphere.

The steps followed in cleaning the samples were:

1. Placing the samples in a bath of carbon tetrachloride to remove surface oils so as not to impede pickling effect in the next step.

2. Allowing the samples to stand in a pickling acid for approximately one hour to remove any oxides on the surface.

3. Neutralizing the surface of the sample by using a solution of soda ash.

4. Rinsing in water to cleanse surface.

5. Dipping in carbon tetrachloride bath to facilitate drying.

6. Rubbing with an oil-saturated cloth to place a thin protective coating of oil on the sample in order to prevent

any future corroding.

After being subjected to the carburizing atmosphere in the furnace for one hour, sample A was removed; after two hours, sample B; and, after three hours, sample C. When taken from the furnace, the samples were placed in a container of asbestos and allowed to cool.

To determine the depth of case, each sample was bisected with an abrasive cut off wheel; placed in a holder; rough ground on a grinder; semi-rough ground on grinding belts of 180 and 240 grit; and then fine ground on grit of 0 and 00 emery grit.

In order to study the microstructure of the samples, they had to have a surface which approached a mirror finish. The desired surface on the samples was achieved by polishing them on wet laps using 400, 500, and 600 grit of aluminum oxide. The samples were then etched with 4 per cent nital, and placed under a microscope for a preliminary observation of the case depth, and any irregularities that may have occurred during carburizing. The last step was the measuring of the samples' case depth and its zones of various carbon content.

It was noticed in early runs that carburizing samples from this furnace were heavy in eutectoid and hypoeutectoid area but nil in hypereutectoid area. It was found that the rate of cooling of the sample was such that the time allowed for the precipitation of cementite was inadequate and thus the hypereutectoid structure did not develop. In order to facilitate slow cooling, the procedure was changed so that each sample was placed in the carburizing furnace in sequence of carburizing time and withdrawn from the furnace together. They were immediately transferred to a small preheated cooling furnace which had been placed next to the carburizing furnace. The preheat temperature of the cooling furnace was approximately 1500 degrees F. The cooling furnace was then shut off, allowing the samples and furnace to cool slowly. Slow cooling extended the precipitation time and guaranteed complete cementite precipitation in each sample.

When conducting carburizing runs on light, medium, and heavy loads of sheet steel, the same procedures were followed as those used in carburizing samples. The only exceptions being that all loads were carburized using identical flows of 3000 cc of gas and 500 cc of air per minute at 1650 degrees F. for three hours. Measuring case depth of sheet steel loads was accomplished by removing a one inch square from the top, middle, and bottom of three different sheets strategically located in the furnace. Each evening the charcoal tube was recharged and the silica jel was dried every weekend.

METHODS OF ANALYSIS

Dew Point Determination

As illustrated in Plate VI, the apparatus used to determine the dew point of effluent gases from the carburizing retort consisted of a large glass tube with a rubber stopper at the open end. This stopper had three holes in it, one which supported a smaller test tube containing alcohol, a second hole which held an intake tube, and a third hole which was used as an exhaust outlet.

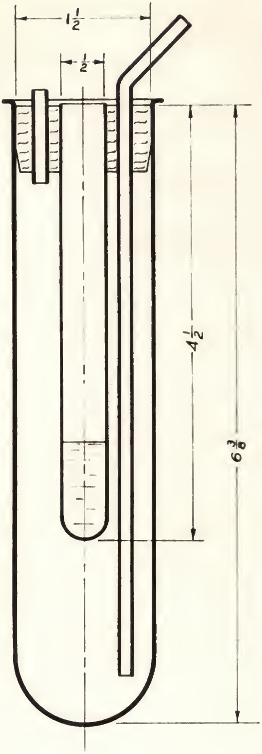
One end of a hose was secured to the exhaust outlet of the furnace and the other end was attached to the intake tube of the dew point determinator. The exhaust gas was allowed to circulate throughout the tube in order to purge any air or moisture that might be present. Following this, small pieces of dry ice were dropped into the alcohol to lower the temperature sufficiently to allow moisture to condense on the outside of the alcohol tube. At this point, the indicated temperature of the alcohol was recorded from a thermometer which had been placed in the alcohol tube immediately following the dry ice.

Two dew point readings were taken, one at the beginning of each run and one an hour later in order to check the moisture content of the furnace atmosphere. The average of the readings was then recorded on the data sheet.

EXPLANATION OF PLATE VI

Apparatus for determining the dew point of the carburizing atmosphere.

PLATE VI



Gas Analysis

In the analysis of the effluent gas of the carburizing furnace a Burrell VT Cabinate Gas analysis apparatus was used. This particular analyzer consisted of two absorption pipettes containing oxysorb for the absorption of oxygen and one absorption pipette containing pottassium hydroxide for the absorption of carbon dioxide. The apparatus also had a catalytic tube which was used for the oxidation of the combustible gases.

The methods and procedures used by the author are illustrated and explained in the Burrell catalog (3). This catalog also gives the methods of calculating percentages of the gases produced by the reactions within the carburizing furnace. These gases are carbon dioxide, carbon monoxide, methane, hydrogen and oxygen.

In recent years, a method of determining the carburizing potential of furnace atmospheres has been developed. The carburizing potential is determined by measuring the change in resistance of a wire as a result of being subjected to a carburizing atmosphere.

Leads and Northrop have developed this method to a point where it is used to continually measure and control the change in carburizing potential of the furnace atmosphere. This method can be used only in atmospheres free from sulphur. In a method employed by Westinghouse, the exhaust gases from the carburizing furnace are passed over a wire which has been preheated by an electric current to a temperature equal to that of the furnace. This wire must be replaced before another measurement of resistance is made.

Case Depth Determination

There are three standard methods, with various limitations, employed in the determination of the case depth of carburized parts. These methods of case depth determination (19) are by: (1) chemical analysis; (2) measurement of hardness; and (3) direct measurement.

The method of chemical analysis of case depth is accomplished by shaving .005 of an inch off of the case and subjecting these shavings to chemical analysis to determine the carbon content. This process is repeated until the carbon content is equal to that of the base metal. The number of shaves necessary is multiplied by .005 to give the case depth. This process is time-consuming but is used quite extensively in research.

The method of hardness measurement to determine case depth is accomplished by taking hardness readings at close intervals on cross sections of samples. The point where there is a marked decrease in hardness shows where the case ends. To determine the case depth, the number of hardness readings taken is multiplied by the distance between hardness readings. These samples must be in the hardened condition.

There are three methods of direct determination: rough fracture, rough polish of cross sections, and high polish of cross sections. The latter was used by the author. This method required a mirror finish on the cross sectioned sample. The method used in obtaining the desired finish on the sample is explained in detail under the section of this thesis entitled "Experimental Procedure".

After polishing and etching, the sample was placed on a metallograph. The microstructure image of the carburized case was projected onto a calibrated ground glass screen. By using a ten power eye piece, correct bellows setting, proper ocular lense, and the calibrated ground glass screen, the author was able to read the case depths directly in thousands of an inch.

Case depth readings were taken of three separate zones: the hypoeutectoid zone, where ferrite and pearlite were observed; the eutectoid zone, where only pearlite was observed; and the hypereutectoid, where pearlite and free cementite were observed (Fig. 1).

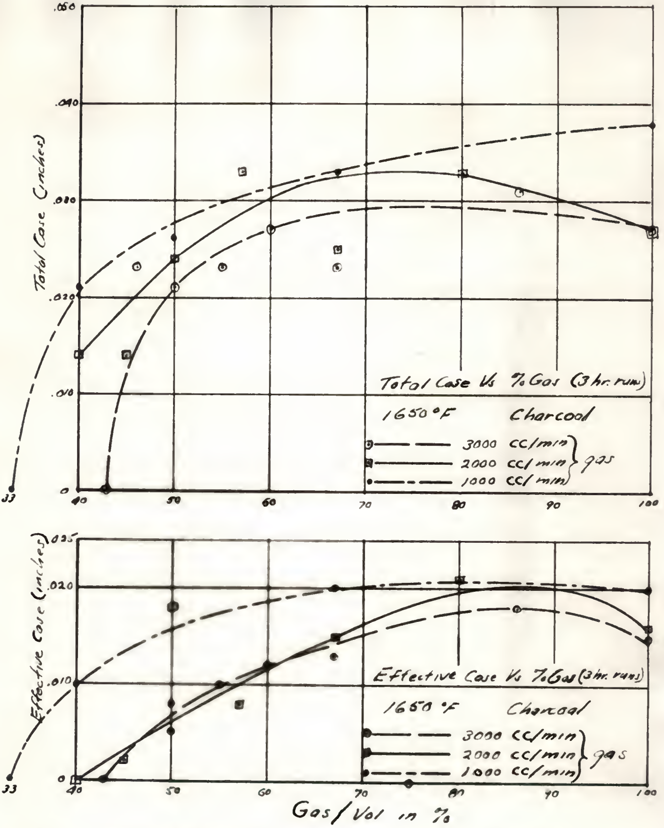


Fig. 3. Total and effective case depth vs. per cent gas at 1650°F. with flows of 1000, 2000, and 3000 cc gas/min. with charcoal.

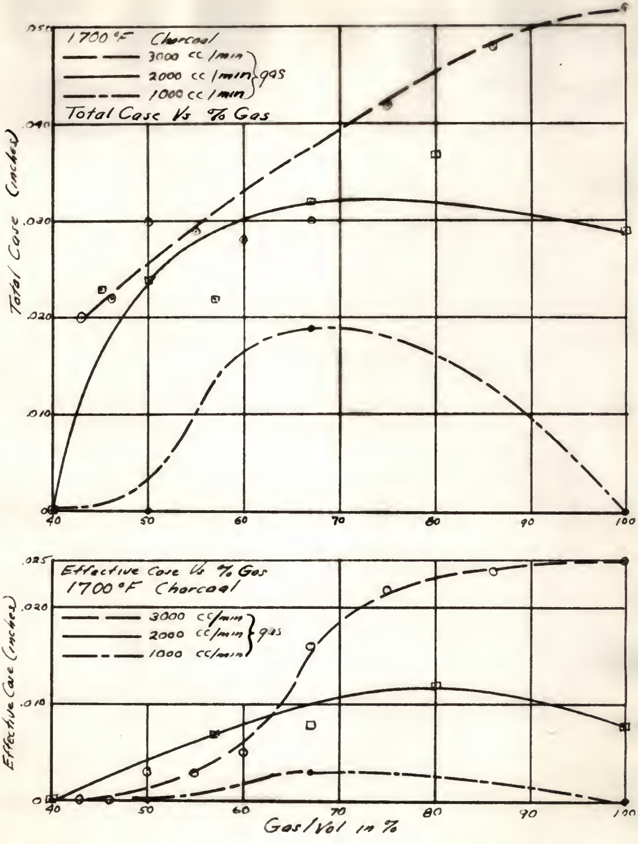


Fig. 4. Total and effective case depth vs. per cent gas at 1700° F. with flows of 1000, 2000, and 3000 cc of gas/min. with charcoal.

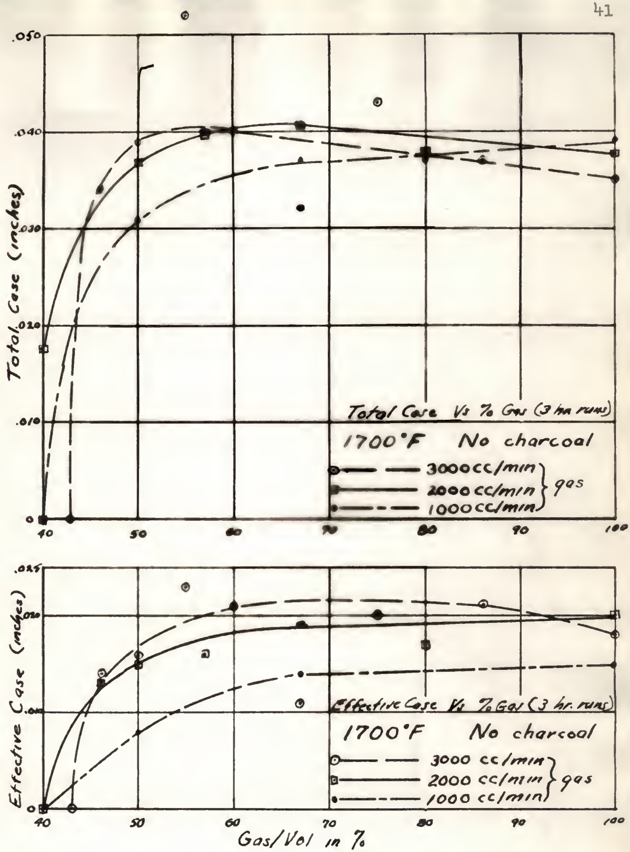


Fig. 5. Total and effective case depth vs. per cent of gas with flows of 1000, 2000, and 3000 cc of gas/min. at 1700° F. and no charcoal.

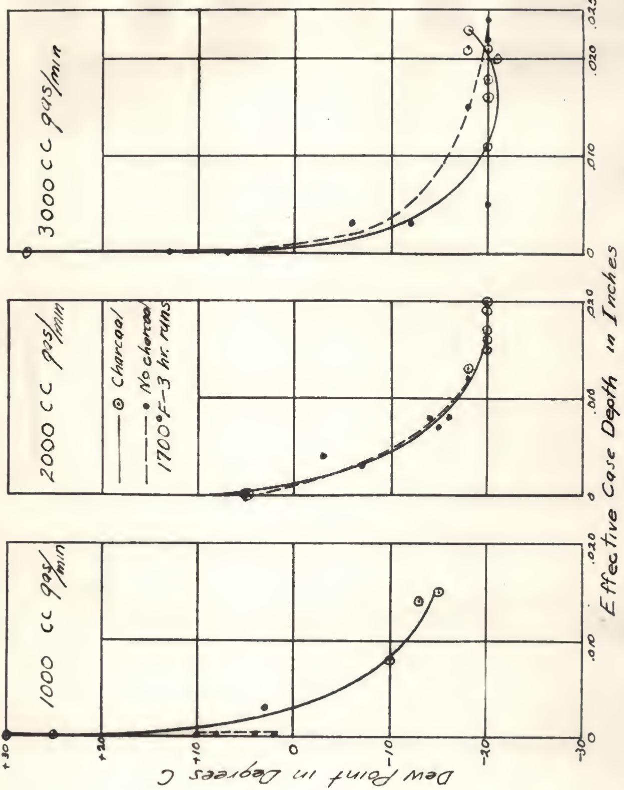


Fig. 6. Effective case depth vs. dew point in °C. with flows of 1000, 2000, and 3000 cc of gas/min. at 1700° F. with and without charcoal.

Table 1. Temperature checks of various points in furnace retort by use of therma couple (no charcoal in charcoal tube).

Date	Time of day	Milivolts top	Temp. °F. top	Milivolts bottom	Temp. °F. bottom	Furnace temp. °F.
Sept. 24, 1951	1:09	0	0	0	0	0
	1:29	9.70	495	9.90	503	500
	1:42	13.95	681	16.75	802	830
	2:09	20.25	940	22.90	1063	1180
	2:19	21.45	1005	24.27	1120	1240
	2:27	22.50	1045	25.25	1163	1280
	2:39	23.95	1108	26.85	1235	1350
	2:54	25.62	1180	28.60	1309	1425
	3:06	27.08	1245	29.82	1360	1480
	3:24	28.80	1315	31.58	1438	1570
	4:11	31.36	1428	33.55	1523	1650
	4:39	31.85	1450	34.06	1545	1650_1 2
Sept. 25, 1951	8:05	33.90	1540	36.60	1658	1650
	8:37	34.06	1547	36.40	1650	1650^3
	8:40	34.42	1562	36.15	1635	1650^4
	8:45	34.44	1564	36.22	1638	1650
	9:04	34.40	1560	36.10	1635	1650
	9:24	33.90	1540	36.05	1633	1650
	9:30	34.45	1563	36.25	1639	1650
	10:20	35.17	1595	37.20	1685	1700
	10:25	35.36	1605	37.10	1680	1700
	10:35	35.36	1605	3710	1680	1700
	10:41	35.94	1630	37.97	1720	1748
	10:51	36.38	1649	38.35	1738	1750
	11:01	36.35	1645	38.36	1738	1750
	11:11	35.00	1588	36.70	1653	1650^5
	11:45	34.75	1578	36.55	1651	1650_6
	2:30	.25		.25		
	3:03	20.84	760	21.36	775	1050
	3:10	21.78	790	22.11	800	1100

Table 1 (concl.).

Date	Time of day	Milivolts top	Temp. °F. top	Milivolts bottom	Temp. °F. bottom	Furnace temp. °F.
Sept. 25, 1951	3:30	24.64	1140	25.16	1160	1220
	3:45	26.66	1225	27.25	1250	1310
	4:00	28.95	1325	29.25	1335	1400
	4:25	31.48	1443	32.28	1460	1610
	5:00	36.60	1660	37.48	1700	1700

1 The furnace was set in operation at 12:00 (midnight) so as to completely heat the top of the furnace.

2 Checked with no air flowing and fan off.

3 Checked with air flowing and fan off.

4 These readings and subsequent ones were checked with air flowing and fan on.

5 Temperature was lowered to 1650° F. to determine if the temperature differential remains the same with the top of the furnace preheated above 1650° F.

6 Refractory material was added to the underside of lid to increase heat retention of the furnace retort.

Table 2. Complete data for experiment.

Run	Sample	Hyper.	Eut.	Hypo.	Total case	Flows		Temp. F.	Dew point °C.	C O_2 %	Length of run (hours)	Change in volume per minute
						Air cc/min	Gas cc/min.					
1	A	0	.008	.005	.013	0	1000	1650	-7.3	0	1	.033
	B	0	.015	.006	.021	"	"	"	"	0	2	"
	C	.002	.018	.012	.032	"	"	"	"	0	3	"
2	A	0	.006	.007	.013	500	"	"	-12.7	.40	1	.049
	B	0	.012	.008	.020	"	"	"	"	"	2	"
	C	.003	.017	.013	.033	"	"	"	"	"	3	"
3	A	0	0	.007	007	1000	"	"	-6.3	.21	1	.066
	B	0	.009	.007	.018	"	"	"	"	"	2	"
	C	0	.018	.019	.037	"	"	"	"	"	3	"
4[1]	A	0	.004	.011	.015	1000	1000	1650	-4	.21	1	.066
	B	0	.006	.014	.020	"	"	"	"	"	2	"
	C	0	.008	.018	.026	"	"	"	"	"	3	"
5	A	0	0	.003	.003	1500	"	"	-7	.60	1	.082
	B	0	0	.008	.008	"	"	"	"	"	2	"
	C	0	.010	.011	.021	"	"	"	"	"	3	"
6	A	0	0	0	0	2000	"	"	-4	.82	1	.099
	B	0	0	0	0	"	"	"	"	"	2	"
	C	0	0	0	0	"	"	"	"	"	3	"
7	A	0	.007	.006	.013	0	2000	1650	-15	0	1	.066
	B	0	.012	.009	.021	0	"	"	"	"	2	"
	C	0	.016	.011	.027	0	"	"	"	"	3	"

Table 2 (cont.).

Run	Sample	Hyper.	Eut.	Hypo.	Total case	Flows Air cc/min	Flows Gas cc/min.	Temp. °F.	Dew point °C.	C O$_2$ %	Length of run (hours)	Change in volume per minute
8	A	0	.008	.012	.020	500	2000	1650	-14	0	1	.082
	B	.001	.013	.012	.026	"	"	"	"	0	2	"
	C	.001	.020	.012	.033	"	"	"	"	0	3	"
9	A	0	.006	.004	.010	1000	"	"	-18	.20	1	.099
	B	0	.011	.006	.017	"	"	"	"	"	2	"
	C	.001	.019	.010	.025	"	"	"	"	"	3	"
10	A	0	.003	.007	.010	1500	"	"	-19	.59	1	.115
	B	0	.007	.011	.018	"	"	"	"	"	2	"
	C	0	.008	.024	.032	"	"	"	"	"	3	"
11	A	0	.003	.006	.009	2000	2000	1650	-16	.20	1	.134
	B	0	.011	.008	.019	"	"	"	"	"	2	"
	C	.002	.016	.006	.024	"	"	"	"	"	3	"
12	A	0	.007	.007	.014	2500	"	"	-18	"	1	.150
	B	0	.017	.008	.025	"	"	"	"	"	2	"
	C	.002	.017	.014	.033	"	"	"	"	"	3	"
13^2	A	0	0	.007	.007	"	"	"	-6	.99	1	.150
	B	0	0	.013	.013	"	"	"	"	"	2	"
	C	0	.002	.012	.014	"	"	"	"	"	3	"
14	A	0	0	.003	.003	3000	2000	1650	"	"	1	.166
	B	0	0	.010	.010	"	"	"	"	.40	2	"
	C	0	0	.014	.014	"	"	"	"	"	3	"

Table 2 (cont.).

Run	Sample	Hyper.	Eut.	Hypo.	Total case	Flows Air cc/min	Flows Gas cc/min.	Temp. °F.	Dew point °C.	C O$_2$ %	Length of run (hours)	Change in volume per minute
15	A	.001	.006	.007	.014	0	3000	1650	-9	0	1	.099
	B	.006	.007	.008	.021	"	"	"	"	"	2	"
	C	.008	.007	.012	.027	"	"	"	"	"	3	"
16	A	.001	.007	.008	.016	500	"	"	-11	"	1	.115
	B	.006	.009	.013	.028	"	"	"	"	"	2	"
	C	.005	.013	.013	.031	"	"	"	"	"	3	"
17	A	0	0	0	0	6000	"	"	-1	.99	1	.300
	B	0	0	0	0	"	"	"	"	"	2	"
	C	0	0	0	0	"	"	"	"	"	3	"
18	A	0	.001	.008	.009	1000	3000	1650	-21	"	1	.134
	B	0	.007	.013	.020	"	"	"	"	"	2	"
	C	.004	.009	.010	.023	"	"	"	"	"	3	"
19	A	0	0	.005	.005	1500	"	"	"	.40	1	.150
	B	0	.006	.011	.017	"	"	"	"	"	2	"
	C	0	.012	.015	.027	"	"	"	"	"	3	"
20	A	0	.003	.007	.010	2000	"	"	-20	0	1	.166
	B	0	.004	.011	.015	"	"	"	"	"	2	"
	C	0	.010	.013	.023	"	"	"	"	"	3	"
21	A	0	0	.008	.008	2500	3000	1650	-17	"	1	.182
	B	0	.005	.007	.012	"	"	"	"	"	2	"
	C	0	.005	.016	.021	"	"	"	"	"	3	"

Table 2 (cont.).

Run	Sample	Hyper.	Eut.	Hypo.	Total case	Flows Air cc/min	Flows Gas cc/min.	Temp. °F.	Dew point °C.	C O$_2$ %	Length of run (hours)	Change in volume per minute
22	A	0	0	.005	.005	3000	3000	1650	-7	.99	1	.199
	B	0	0	.013	.013	"	"	"	"	"	2	"
	C	0	0	.023	.023	"	"	"	"	"	3	"
23	A	0	0	0	0	3500	"	"	-5	0	1	.215
	B	0	0	0	0	"	"	"	"	"	2	"
	C	0	0	0	0	"	"	"	"	"	3	"
24[3]	A	0	0	.023	.023	500	"	"	-6	"	1	.115
	B	0	0	.026	.026	"	"	"	"	"	2	"
	C	0	.001	.028	.029	"	"	"	"	"	3	"
25	A	0	0	.012	.012	500	3000	1650	"	"	1	.115
	B	0	.008	.019	.027	"	"	"	"	"	2	"
	C	0	.006	.024	.030	"	"	"	"	"	3	"
26	A	0	0	.020	.020	500	"	"	"	0	1	.115
	B	0	0	.023	.023	"	"	"	"	"	2	"
	C	0	0	.024	.024	"	"	"	"	"	3	"
27	A	0	.007	.018	.025	500	"	"	-9	"	1	.115
	B	0	.007	.023	.030	"	"	"	"	"	2	"
	C	0	.009	.024	.033	"	"	"	"	"	3	"
28[4]						500	3000	1650	-8	0	3	.115
29						500	3000	1650	-17	0	3	.115

Table 2 (cont.).

Run	Sample	Hyper.	Eut.	Hypo.	Total case	Flows		Temp. °F.	Dew point °C.	C O_2 %	Length of run (hours)	Change in volume per minute
						Air cc/min	Gas cc/min					
30						500	3000	1650	-17	0	3	.115
31[5]						500	3000	1650	-19	0	3	.115
32[6]	A	0	0	0	0	0	1000	1700	10		1	.033
	B	0	0	0	0	0	"	"	"	"	2	"
	C	0	0	0	0	0	"	"	"	"	3	"
33	A	0	.002	.007	.009	500	1000	1700	3	"	1	.049
	B	0	0	.017	.017	"	"	"	"	"	2	"
	C	0	.003	.016	.019	"	"	"	"	"	3	"
34	A	0	0	0	0	1000	1000	1700	2	0	1	.066
	B	0	0	0	0	"	"	"	"	"	2	"
	C	0	0	0	0	"	"	"	"	"	3	"
35	A	0	0	0	0	1500	1000	1700	4	"	1	.082
	B	0	0	0	0	"	"	"	"	"	2	"
	C	0	0	0	0	"	"	"	"	"	3	"
36	A	0	0	0		2000	1000	1700	8	"	1	.099
	B	0	0	0		"	"	"	"	"	2	"
	C	0	0	0		"	"	"	"	"	3	"
37	A	0	0	.017	.017	0	2000	1700	-14	"	1	.066
	B	0	.006	.020	.026	"	"	"	"	"	2	"
	C	0	.008	.021	.029	"	"	"	"	"	3	"

Table 2 (cont.).

Run	Sample	Hyper.	Eut.	Hypo.	Total case	Flows Air cc/min	Flows Gas cc/min.	Temp. °F.	Dew point °C.	C O_2 %	Length of run (hours)	Change in volume per minute
38	A	0	0	.017	.017	500	2000	1700	-18		1	.082
	B	0	.002	.022	.024	"	"	"	"		2	"
	C	0	.012	.025	.037	"	"	"	"		3	"
39	A	0	0	.015	.015	1000	2000	1700	-16		1	.099
	B	0	.003	.023	.025	"	"	"	"		2	"
	C	0	.008	.024	.032	"	"	"	"		3	"
40	A	0	0	.012	.012	1500	2000	1700	-15		1	.115
	B	0	.007	.010	.017	"	"	"	"		2	"
	C	0	.007	.015	.022	"	"	"	"		3	"
41	A	0	0	.013	.013	2000	2000	1700	-7		1	.134
	B	0	0	.019	.019	"	"	"	"		2	"
	C	0	.003	.021	.024	"	"	"	"		3	"
42	A	0	0	.018	.018	2500	2000	1700	-3		1	.150
	B	0	0	.020	.020	"	"	"	"		2	"
	C	0	.002	.021	.023	"	"	"	"		3	"
43	A	0	0	0	0	3000	2000	1700	5		1	.166
	B	0	0	0	0	"	"	"	"		2	"
	C	0	0	0	0	"	"	"	"		3	"
44	A	.006	.005	.014	.025	0	3000	1700	-30		1	.099
	B	.012	.006	.017	.035	"	"	"	"		2	"
	C	.015	.010	.027	.052	"	"	"	"		3	"

Table 2 (cont.).

Run	Sample	Hyper.	Eut.	Hypo.	Total case	Flows Air cc/min	Flows Gas cc/min.	Temp. °F.	Dew point °C.	C O_2 %	Length of run (hours)	Change in volume per minute
45	A	.006	.007	.008	.021	500	3000	1700	-20		1	.115
	B	.011	.007	.014	.032	"	"	"	"		2	"
	C	.015	.009	.024	.048	"	"	"	"		3	"
46	A	0	.005	.016	.021	1000	3000	1700	-20		1	.134
	B	0	.007	.018	.025	"	"	"	"		2	"
	C	.015	.007	.020	.042	"	"	"	"		3	"
47	A	0	.006	.009	.015	1500	3000	1700	-18		1	.150
	B	.003	.006	.013	.022	"	"	"	"		2	"
	C	.009	.007	.014	.030	"	"	"	"		3	"
48	A	0	.003	.016	.019	2000	3000	1700	-20		1	.166
	B	0	.004	.020	.024	"	"	"	"		2	"
	C	0	.005	.023	.028	"	"	"	"		3	"
49	A	0	.002	.020	.022	2500	3000	1700	-12		1	.182
	B	0	.002	.023	.025	"	"	"	"		2	"
	C	0	.003	.026	.029	"	"	"	"		3	"
50	A	0	0	.015	.015	3000	3000	1700	-6		1	.199
	B	0	0	.024	.024	"	"	"	"		2	"
	C	0	.003	.024	.030	"	"	"	"		3	"
51[7]	A	0	0	.013	.015	3500	3000	1700	7		1	.215
	B	0	0	.017	.017	"	"	"	"		2	"
	C	0	0	.022	.022	"	"	"	"		3	"

Table 2 (cont.).

Run	Sample	Hyper.	Eut.	Hypo.	Total case	Flows		Temp. °F.	Dew point °C.	C O$_2$ %	Length of run (hours)	Change in volume per minute
						Air cc/min	Gas cc/min.					
52	A	0	0	.003	.003	4000	3000	1700	13		1	.233
	B	0	0	.016	.016	"	"	"	"		2	"
	C	0	0	.020	.020	"	"	"	"		3	"
53[8,9]	A	.002	.004	.014	.020	0	1000	1700	21		1	.033
	B	.004	.005	.016	.025	"	"	"	"		2	"
	C	.007	.008	.022	.037	"	"	"	"		3	"
54	A	0	0	0	0	500	1000	1700	28		1	.099
	B	0	0	0	0	"	"	"	"		2	"
	C	0	0	0	0	"	"	"	"		3	"
55[10]	A	0	0	.016	.016	1000	1000	1700	28		1	.066
	B	0	0	.022	.022	"	"	"	"		2	"
	C	0	0	.032	.032	"	"	"	"		3	"
56	A	0	0	0	0	1500	1000	1700	25		1	.082
	B	0	0	0	0	"	"	"	"		2	"
	C	0	0	0	0	"	"	"	"		3	"
57	A	0	0	0	0	2000	1000	1700	30		1	.099
	B	0	0	0	0	"	"	"	"		2	"
	C	0	0	0	0	"	"	"	"		3	"
58	A	.005	.006	.010	.021	0	3000	1700	-20	0	1	.099
	B	.008	.004	.014	.026	"	"	"	"	"	2	"
	C	.010	.008	.017	.035	"	"	"	"	"	3	"

Table 2 (cont.).

Run	Sample	Hyper.	But.	Hypo.	Total case	Flows Air cc/min	Flows Gas cc/min.	Temp. °F.	Dew point °C.	C O_2 %	Length of run (hours)	Change in volume per minute
59	A	.008	.004	.012	.024	500	3000	1700	-20	0	1	.115
	B	.007	.007	.015	.029	"	"	"	"	"	2	"
	C	.013	.008	.016	.037	"	"	"	"	"	3	"
60	A	0	.010	.014	.024	1000	3000	1700	-21	0	1	.134
	B	.004	.010	.018	.032	"	"	"	"	"	2	"
	C	.010	.010	.023	.043	"	"	"	"	"	3	"
61	A	.002	.005	.013	.020	1500	3000	1700	-20	0	1	.150
	B	.003	.008	.019	.030	"	"	"	"	"	2	"
	C	.003	.008	.021	.032	"	"	"	"	"	3	"
62	A	0	.008	.007	.015	2000	3000	1700	-18	0	1	.166
	B	.008	.007	.015	.030	"	"	"	"	"	2	"
	C	.015	.006	.019	.040	"	"	"	"	"	3	"
63	A	.005	.007	.017	29	2500	3000	1700	-18	0	1	.182
	B	10	.008	.016	34	"	"	"	"	"	2	"
	C	.012	.011	.028	52	"	"	"	"	"	3	"
64	A	0	0	.024	.024	3000	3000	1700	-20	0	1	.199
	B	0	.014	.020	.034	"	"	"	"	"	2	"
	C	0	.016	.023	.039	"	"	"	"	"	3	"
65	A	0	.007	.014	.021	3500	3000	1700	20	1.20	1	.215
	B	0	.012	.015	.027	"	"	"	"	"	2	"
	C	0	.014	.020	.034	"	"	"	"	"	3	"

Table 2 (cont.).

Run	Sample	Hyper.	Eut.	Hypo.	Total case	Flows		Temp. °F.	Dew point °C.	C O$_2$ %	Length of run (hours)	Change in volume per minute
						Air cc/min	Gas cc/min.					
66	A	0	0	0	0	4000	3000	1700	-28	3.23	1	.233
	B	0	0	0	0	"	"	"	"	"	2	"
	C	0	0	0	0	"	"	"	"	"	3	"
67	A	0	.006	.015	.021	0	2000	1700	-20	0	1	.066
	B	.008	.007	.018	.033	"	"	"	"	"	2	"
	C	.011	.009	.018	.038	"	"	"	"	"	3	"
68	A	0	.006	.011	.017	500	2000	1700	-20	0	1	.082
	B	.009	.006	.015	.030	"	"	"	"	"	2	"
	C	.009	.008	.021	.038	"	"	"	"	"	3	"
69	A	0	.009	.015	.024	1000	2000	1700	-20	0	1	.099
	B	.007	.008	.014	.029	"	"	"	"	"	2	"
	C	.013	.006	.023	.041	"	"	"	"	"	3	"
70	A	0	.010	.013	.023	1500	2000	1700	-20	0	1	.115
	B	.009	.005	.018	.032	"	"	"	"	"	2	"
	C	.008	.008	.024	.040	"	"	"	"	"	3	"
71	A	0	.007	.015	.022	2000	2000	1700	-20	0	1	.134
	B	.003	.008	.016	.027	"	"	"	"	"	2	"
	C	.006	.009	.022	.037	"	"	"	"	"	3	"
72	A	0	.007	.014	.021	2500	2000	1700	-18	0	1	.150
	B	0	.010	.020	.030	"	"	"	"	"	2	"
	C	0	.013	.024	.037	"	"	"	"	"	3	"

Table 2 (concl.).

Run	Sample	Hyper.	Eut.	Hypo.	Total case	Flows Air cc/min	Flows Gas cc/min.	Temp. °F.	Dew point °C.	C O_2 %	Length of run (hours)	Change in volume per minute
73	A	0	0	.014	.014	3000	2000	1700	5	.41	1	.166
	B	0	0	.016	.016	"	"	"	"	"	2	"
	C	0	0	.018	.018	"	"	"	"	"	3	"
74[11]	A	.004	.006	.015	.025	0	1000	1700	-15	0	1	.033
	B	.005	.008	.018	.031	"	"	"	"	"	2	"
	C	.007	.008	.024	.039	"	"	"	"	"	3	"
75[12]	A	0	.008	.014	.022	500	1000	1700	-13	0	1	.049
	B	0	.011	.022	.033	"	"	"	"	"	2	"
	C	.003	.011	.023	.037	"	"	"	"	"	3	"
76[13]	A	0	.005	.013	.018	1000	1000	1700	-10	0	1	.066
	B	0	.003	.018	.021	"	"	"	"	"	2	"
	C	0	.008	.023	.031	"	"	"	"	"	3	"

[1] Check run for number 3.

[2] Check run for number 12.

[3] Runs 24 to 30 were made on 3 square feet of surface area.

[4] No sample was included in runs 28, 29, 30, and 31; these runs were made to determine circulating and heating uniformity.

[5] Run 31 was made on 6 square feet of surface area.

[6] This was a weak case with carbon not over .10%.

[7] Maximum carbon for run 51 was .4%.

[8] Runs 53 to 76 inclusive had no charcoal in the charcoal tube and lean flows where run first.

[9] Check runs for 53, 54, and 55 are runs 74, 75, and 76.

[10] There was heavy scale formation on samples.

[11] Check run for number 53.

[12] Check run for number 54.

[13] Check run for number 55.

DISCUSSION OF RESULTS

In presenting the data on case depth in Figs. 3, 4, 5, and 6, the depths given are measurements of the combined hypereutectoid and eutectoid zones. These zones were measured because the hypoeutectoid zone and core (Fig. 1) have a low carbon content and they, therefore, cannot be hardened sufficiently nor will they develop proper wear resistance. Furthermore, the hypereutectoid and eutectoid zones are sharply defined and can be measured with greater accuracy than the total case depths. In Figs. 3, 4, and 5, total case depths are also plotted.

To show the effect of having gas and air pass over hot charcoal (1700 degrees F.) in the charcoal tube before entering the main carburizing compartment of the furnace, two series of runs were made, one with charcoal and one without charcoal (Table 2). In each series the air gas ratio and the flow rates were varied. Figs. 3 and 4 show the case depths produced when charcoal was used while Fig. 6 shows those produced without charcoal.

Figs. 3, 4, and 5 show that irrespective of total flows, the percentage of gas per total volume of furnace atmosphere must equal or exceed 45 per cent in order to produce a case. They also show that 80 per cent gas per total volume gave the deepest and most uniform effective cases for various flows.

Fig. 3 shows that at 80 per cent gas per total volume with charcoal in the tube, the variation in effective cases with various flows at 1650° F. was only approximately .003 of an inch. For the same flows, with charcoal, at 1700° F. (Fig. 4) the total difference was .020 of an inch and where no charcoal was used at 1700° F. the difference was .007 of an inch (Fig. 3).

The cause of the large difference of effective case in Fig. 4 may be due to the instability of methane at high temperatures. When the natural gas entered the charcoal tube and came into contact with the heated charcoal it partially dissociated into carbon and hydrogen. To illustrate this point, reference is made to Fig. 3. The curves produced have the same characteristic shapes but represent a smaller difference in effective cases as well as total case depth. The tendency of the curves to be uniform show that at the lower temperature of 1650° F. methane is more stable and less of it decomposes upon contact with the heated charcoal; therefore, more methane is made available to the furnace atmosphere for actual carburizing.

The ideal uniform curves illustrated in Fig. 5 can be attributed to the passing of methane directly to the carburizing media. Since there was no charcoal in the charcoal tube, the methane passed into the furnace with only a very minimum dissociation.

The drop in both total and effective case depth as shown in Figs. 3, 4, and 5 when mixtures approach 100 per cent natural gas can be attributed to the fact that a large part of methane is decomposed producing soot and a high concentration of hydrogen with little or no carbon monoxide. Fig. 4 readily shows the effect of the dissociation of methane with a flow of 1000 cc of gas per minute. Flows of 2000 and 3000 cc of gas contained enough volume to force the gas through the charcoal before a harmful amount of dissociation took place.

A great deal of sooting occurred in the charcoal filled tubes as a result of the dissociation of methane. To correct the sooting and to prevent the break down of methane, a gas-air mixture of 2 to 5 (stoechiometric ratio) could be introduced into the charcoal filled tube and methane introduced directly into the furnace as the carburizing fuel. The air-gas mixture would act as a dilutant and carrier gas for the methane which was directly introduced into the furnace. The purpose of directing the air-gas mixture through the charcoal filled tube is to remove the moisture produced by the burning of methane and air and, also, to remove any moisture that may be present in the air.

As far as the data accumulated for this thesis shows, there were no indications that moisture is necessary in the carburizing atmosphere. The best carburizing was accomplished at medium to high flows and with low dew points (Fig. 6). The effect of time, temperature, and dew point can be seen by reviewing Table 2 in this thesis.

CONCLUSIONS

1. Improper circulation causes "dead spots" to occur in the furnace atmosphere resulting in irregular carburized cases.

2. Water vapor and carbon dioxide must be kept at a minimum in order to achieve satisfactory carburizing.

3. Temperature differences in the furnace retort must be small in order to have satisfactory uniformity in case depth.

4. Effective case depths can be controlled by varying the air gas ratio and time.

5. Kansas natural gas is a strong carburizing agent.

6. The dissociation of methane to carbon when passed over hot charcoal should be minimized.

7. Carburizing can be accomplished when introducing natural gas into a furnace retort (without the aid of charcoal) but only after sufficient sooting has occurred.

8. Dew point is an excellent measurement of the carburizing tendencies of a furnace atmosphere.

9. At low carburizing temperatures, the surface area of the charcoal must be increased to maintain low dew point.

10. Effective case depth is measured accurately and it represents carbon concentrations of beneficial values.

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DEVELOPING A
COMMERCIAL GAS CARBURIZING UNIT
USING KANSAS NATURAL GAS AS THE CARBURIZING MEDIA

by

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A commercial shop size gas carburizing furnace was designed, constructed and tested under various operating conditions. A tube containing charcoal was placed in the furnace retort and used as a special atmosphere generator. Kansas natural gas was used as a carburizing fuel and air was used as a dilutant gas. Sheet steel with surface areas of three and six square feet was carburized as light and medium loads at 1650 degrees F. Samples of S.A.E. 1117 steel were carburized at 1650 degrees and 1700 degrees F. All carburizing was done with flows of 1000, 2000, and 3000 cc of natural gas per minute with various percentages of air added.

Carburizing runs were made with the charcoal tube empty as well as full, for periods of 1, 2, and 3 hours. All carburized samples were allowed to cool in a cooling furnace before being prepared for case depth measurement. Many improvements in design and construction were made on the furnace. The results of the research were tabulated and plotted in a series of four graphs, three of which showed total and effective case depth versus percentage gas and one showing effective case depth versus dew point.