Oct. 4, 1960 O. E. CULLEN ET AL 2,955,062

METHOD FOR CARBURIZING IN A CONTINUOUS FURNACE

Original Filed Feb. 27, 1952 4 Sheets-Sheet 1

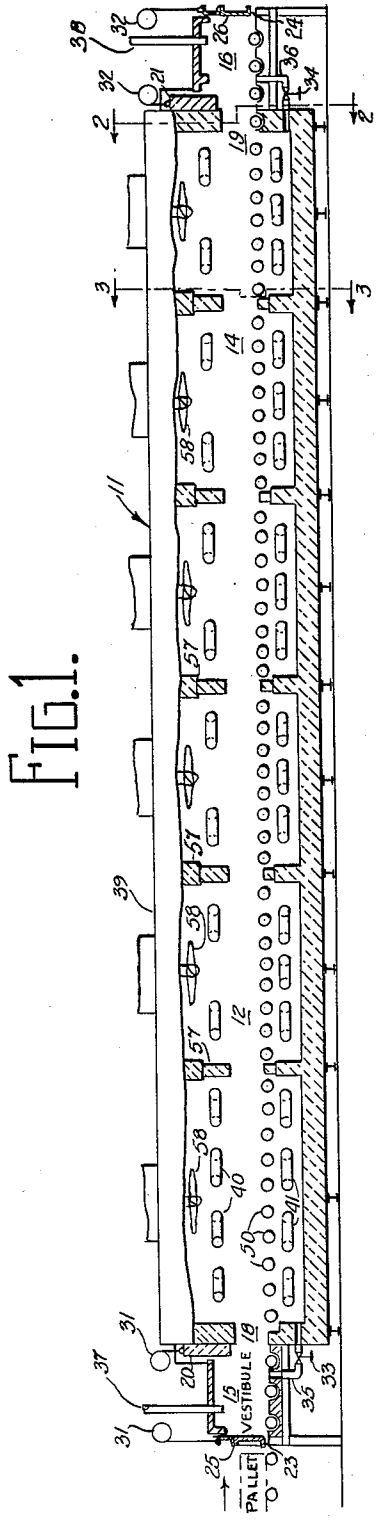


FIG. 1.

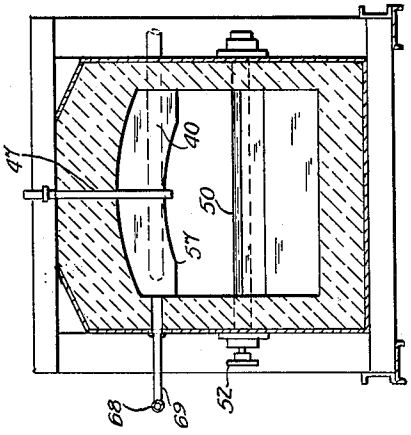


FIG. 3.

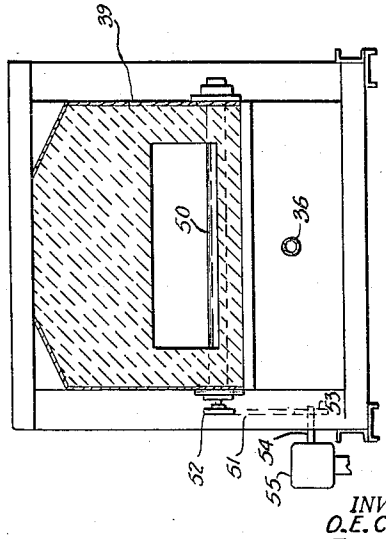


FIG. 2.

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METHOD FOR CARBURIZING IN A CONTINUOUS FURNACE

Original Filed Feb. 27, 1952 4 Sheets-Sheet 2

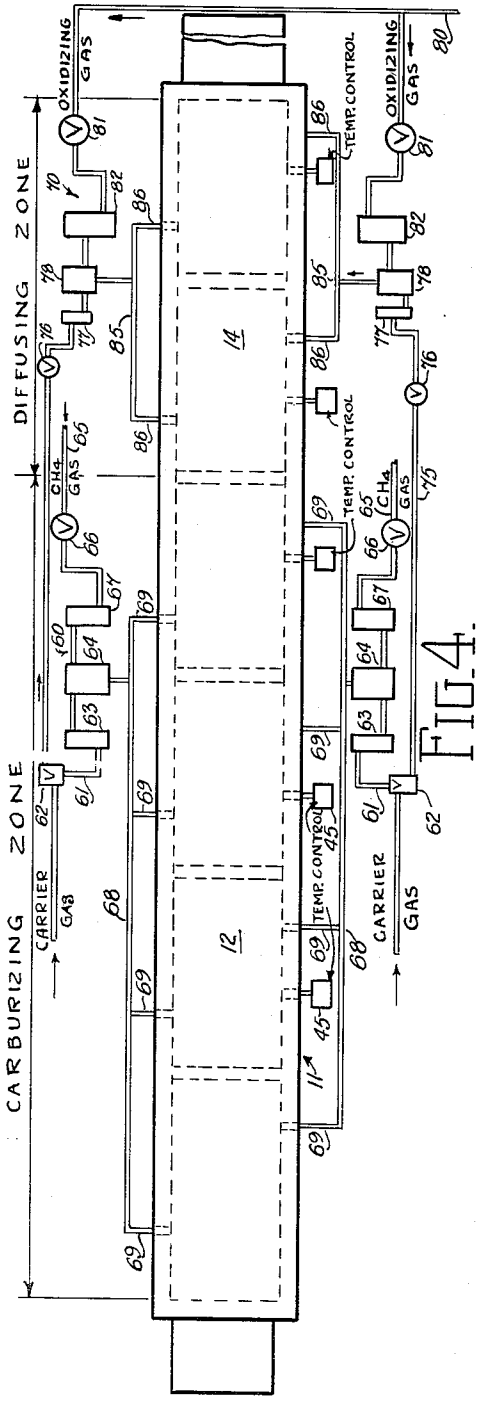


FIG. 4.

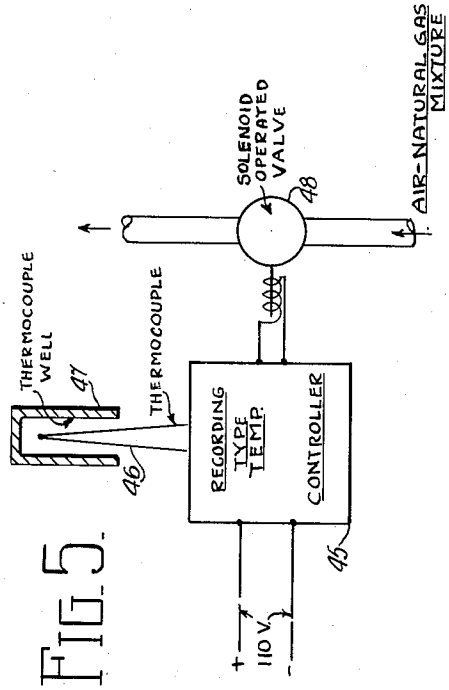


FIG. 5.

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METHOD FOR CARBURIZING IN A CONTINUOUS FURNACE

Original Filed Feb. 27, 1952 4 Sheets-Sheet 3

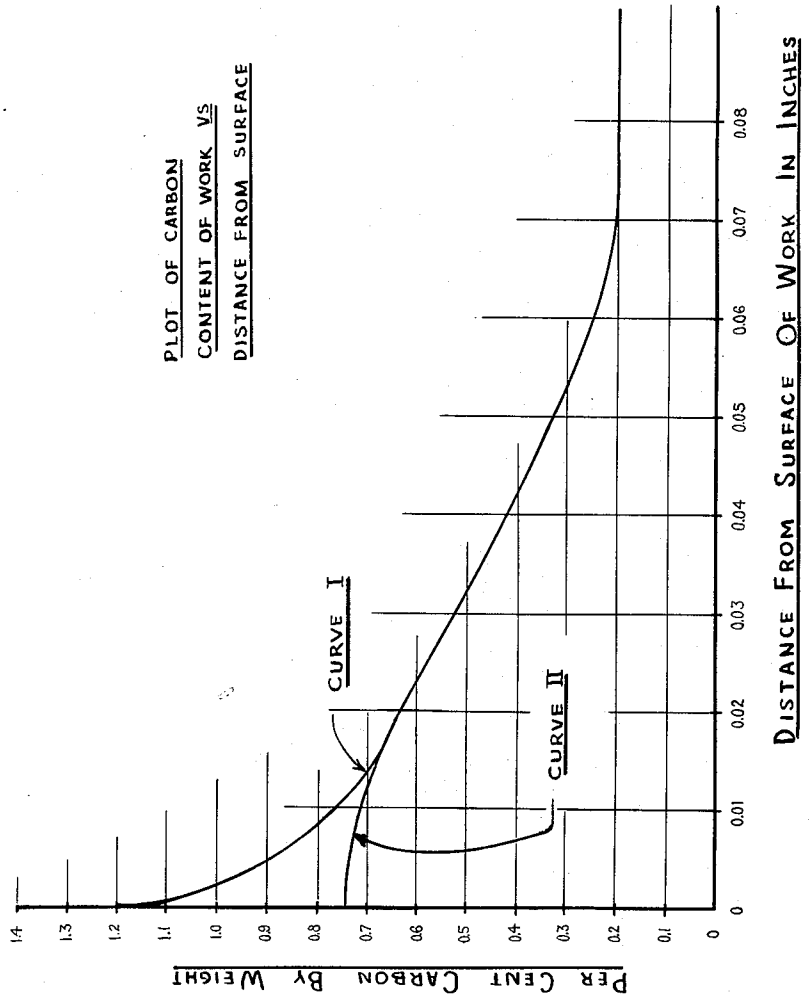


FIG. 6.

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METHOD FOR CARBURIZING IN A CONTINUOUS FURNACE

Original Filed Feb. 27, 1952 4 Sheets-Sheet 4

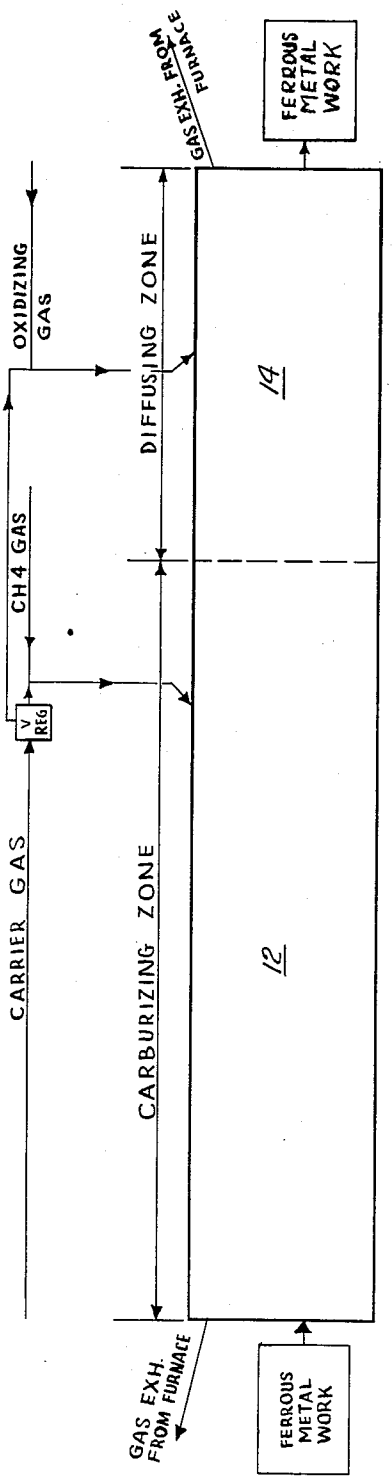


FIG. 7.

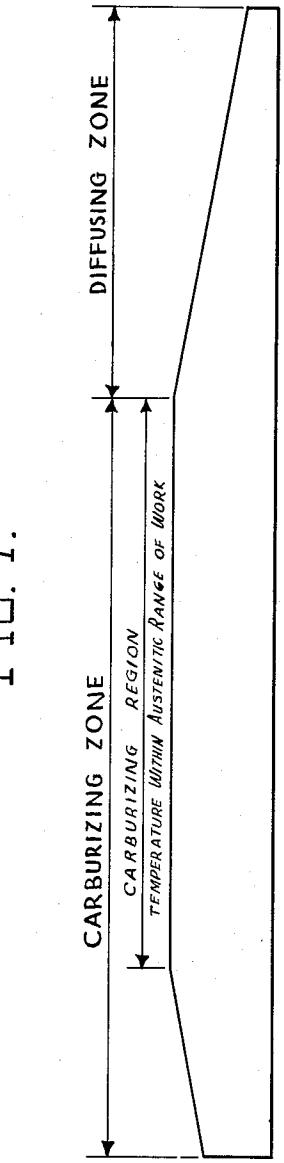


FIG. 8.

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United States Patent Office 2,955,062 Patented Oct. 4, 1960

2,955,062

METHOD FOR CARBURIZING IN A CONTINUOUS FURNACE

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Original application Feb. 27, 1952, Ser. No. 273,696. Divided and this application Mar. 29, 1956, Ser. No. 580,425

4 Claims. (Cl. 148—16.5)

This invention relates to a continuous carburizing furnace and method for continuous carburization.

In the art of carburizing it is well known to use solid material such as charcoal for pack carburizing, and it is known to vary the solids used to obtain variations in the character of the resultant carburized case. It is customary to blend fresh solids with used, or spent, solids for that purpose.

With the advent of gas carburizing processes the mechanics of carburization have become more understandable, and noteworthy advances have been made both in the art of carburization and of carbon restoration to partially decarburized work. These developments stemmed largely from the use of atmospheres consisting essentially of N_2, CO, CO_2, H_2, H_2O and CH_4 or other hydrocarbon equivalents of CH_4. Using such atmospheres soot deposition in a furnace can be largely eliminated, as taught by Turin Patent 2,287,651, and the carbon potential (hereinafter defined) can be controlled.

By proper control of carbon potential and furnace temperature, the surface carbon content of carburized work may be controlled, with resultant desirable metallurgical results, but of course the rate of absorption of carbon into the steel is correspondingly reduced when the carbon potential is reduced, it being understood that the driving force for absorption of carbon into the work is proportional to the excess of the atmosphere carbon potential over the surface carbon content of the work.

"Carbon potential" of a gas, as used herein, and in the appended claims, indicates the carbon content to which that gas will carburize steel if equilibrium is reached; it is customarily measured in percent of carbon in thin strips of steel which have been brought to substantial equilibrium with the gas atmosphere and have a substantially uniform carbon content throughout the strip. Thus, a gas having a carbon potential of 0.80 percent at T° F. would be in equilibrium with steel containing 0.80 percent of carbon at T° F., would carburize steel containing 0.70 percent of carbon at T° F., and would decarburize steel containing 0.90 percent of carbon at T° F. Carbon potential is a function of temperature, however, so that a gas having a carbon potential of 0.80 percent at T° F. would have a carbon potential other than 0.80 at either a lower or a higher temperature. In general, at least within the austenitic range of the work, the carbon potential of a gas of given composition increases with decreases in temperature. Furthermore, known gases having a carbon potential within the range usually required for conventional carburization, i.e., 0.60 to 1.40 percent, at practical carburizing temperatures, decompose badly and deposit large quantities of soot at lower temperatures within the range to which work must often be cooled prior to discharge from the furnace.

The present invention provides in continuous apparatus for carburizing ferrous metal work, an optimum distribution of carbon in the work, and discharge of the work at a desired temperature and after a minimum of time in the furnace for the depth of carburized case desired. The invention can be fully understood from the description which follows, and by reference to the accompanying drawings, in which,

Fig. 1 is an elevation, partially in section, showing mechanical features of a continuous furnace for practicing the invention;

Fig. 2 is a sectional view along the line 2—2 of Fig. 1;

Fig. 3 is a sectional view along the line 3—3 of Fig. 1;

Fig. 4 is a partially diagrammatic plan view of a furnace of Fig. 1 showing means for controlling the atmosphere therein as hereinafter described;

Fig. 5 is a partially schematic view showing a way of effecting temperature control in a furnace of the invention;

Fig. 6 is a graph showing carbon distribution achieved according to the invention and according to continuous prior art carburization methods;

Fig. 7 is a schematic flow diagram showing the steps in the process of the invention; and

Fig. 8 is a schematic representation showing generally the temperature relationships in the process of the invention.

According to the invention, continuous apparatus is utilized for carburizing ferrous metal work to a desired surface carbon content and case depth, effecting an improved carbon distribution in the work, and discharging the carburized work at the desired discharge temperature. The apparatus comprises a controlled atmosphere furnace having a carburizing zone and a diffusing zone, which furnace has means for conveying the work into and through the carburizing zone, and through and from the diffusing zone, means for controlling the furnace temperature to provide, within the carburizing zone, a carburizing region having a substantially constant temperature within the austenitic range of the work, and a temperature within the austenitic range of the work in at least a portion of the diffusing zone, means for creating and maintaining an atmosphere having a high carbon potential in the carburizing zone, and means for creating and maintaining in the diffusing zone an atmosphere having a substantially lower carbon potential, at least as high as the carbon content of the interior of the work but not substantially higher than the desired surface carbon content. Preferably, the carbon potential of the atmosphere in the carburizing zone, at the temperature of the carburizing region, is from 1.00 percent to 1.40 percent, and most desirably it is approximately equal to the carbon content of austenite saturated with carbon at the temperature of the carburizing region. It is also preferred that the carbon potential of the atmosphere in the diffusing zone relative to the work be from $(X-0.30)$ percent to X percent where X is the desired surface carbon content of the work; most desirably, it is approximately X percent.

The furnace shown in Figs. 1, 2, 3, and 4 of the drawings is a continuous apparatus comprising a controlled atmosphere furnace indicated generally at **11**, means indicated generally at **60** in Fig. 4 for creating and maintaining in a carburizing zone **12** of the furnace an atmosphere of any desired carbon potential, and means indicated generally at **70** in Fig. 4 for introducing atmosphere into a diffusing zone **14**. The zones **12** and **14** have, at their outer extremities, vestibules **15** and **16** (Fig. 1) through which atmosphere leaves, and work is admitted to and discharged from the furnace **11**. Openings **18** and **19** in the ends of the furnace are closable by doors **20** and **21**, and vestibule openings **23** and **24** are closable by doors **25** and **26**. The doors **21** and **20** are raised or lowered by chains **29** and **30** driven by sprockets **31** and **32** rotated in any conventional way, not illustrated.

The chains 29 and 30 are made incapable of opening either of the doors 20 and 25 or 21 and 26 until the other is closed, and similarly the inner doors 20 and 21 may not both be opened at the same time. This is preferably accomplished by electrical control interlocks, as is well known. Conduits 35 and 36 with valves 33 and 34 provide passages through which atmosphere is discharged from either end of the furnace into the corresponding vestibule. Second conduits 37 and 38 provide atmosphere exhausts from each vestibule. The conduits 35 and 37 provide atmosphere exhausts from the charge end of the furnace, and the conduits 36 and 38 provide atmosphere exhausts from the discharge end of the furnace.

The furnace 11 is enclosed by a shell 39. In the embodiment of the apparatus of the invention shown in Fig. 1 the furnace is heated by upper radiant tubes 40, and lower radiant tubes 41 in which combustible gases are burned. Temperature in the furnace may be controlled by a series of recording type temperature controllers 45 (see Figs. 4 and 5) each of which is operably attached to one of a series of thermocouples 46 appropriately positioned in the furnace in tubes 47, preferably inserted through the roof thereof with one thermocouple to each of several zones in the furnace. The controllers operate solenoid actuated valves 48 which they open wider when the voltage from a thermocouple 46 indicates a furnace temperature lower than that prescribed, and close partially when the voltage indicates the reverse. The valve 48 regulates the rate of flow of an air-natural gas mixture to the radiant tubes 40 and 41; the combustion of this mixture heats the tubes, and, through them, the furnace. Alternatively, the furnace 11 could be heated by electric resistance elements, or by direct fired burners, as in a muffle furnace, not illustrated, in a conventional manner.

The furnace is provided, also, with a suitable conveyor (Fig. 1) consisting of a series of operably aligned driven rolls 50. The rolls 50 are conveniently driven (see Fig. 2) by chains 51 which mesh with sprockets 52 and 53 attached, respectively, to the rolls 40 and to shafts 54 of motors 55. It is usually feasible and preferred that a single chain 51 mesh with and drive several sprockets 52.

In the furnace shown in Figs. 1, 2, 3 and 4 the furnace 11 is divided into sections in any convenient manner as by a series of jack arches 57 and solid piers thereunder which together serve to substantially divide said sections. In each of the sections is positioned a circulating fan 58 which moves furnace atmosphere in a vertical direction within the respective section. The use of such circulating fans is advantageous, although not essential, as it minimizes the possibility of a stagnant atmosphere pocket of different composition from that contemplated.

The means 60 for creating and maintaining in the carburizing zone 12 an atmosphere of a desired carbon potential consists of a conduit 61 supplied with a carrier gas, hereinafter identified, from a generator or from storage, not illustrated. The gas passes through the conduit 61 in the direction of the arrow (Fig. 4), through a regulating valve 62, which can be operated either manually or automatically, thence into a flow meter 63 where the rate of gas flow is determined visually or automatically, and into a mixer 64. A CH_4 gas, which term is used herein to include natural gas and relatively pure methane, ethane, propane and other hydrocarbons and oxyhydrocarbons that are methane equivalents in that they are known enriching gases for carburizing, can be mixed with the carrier gas in the mixer in any desired proportion, usually not more than 5 percent of the total gas, calculated as methane. Such mixing, if desired, is accomplished by passing the CH_4 gas from storage or from a main, not illustrated, through a conduit 65, in the direction of the arrow, a control valve 66, a flow meter 67 and thence into the mixer 64. The treating gas of desired composition and carbon potential is blended in the mixer 64 and flows from there into a manifold 68, and through conduits 69 into the treating zone. In the embodiment of the invention shown in Fig. 4, the means 60 is duplicated on either side of the furnace 11. The rate at which atmosphere is introduced into the carburizing zone should be such that a small superatmospheric pressure is maintained within the carburizing zone, and should be sufficiently high that substantial reduction in the carbon potential of the atmosphere does not occur because of reaction and absorption of carbon by work in the furnace.

The means 70 for introducing an atmosphere into the diffusing zone receives a carrier gas from the regulating valve 62, which gas flows through a line 75, in the direction of the arrow, through a control valve 76, and through a flow meter 77, and into a mixer 78. The means 70 also receives a potential controlling gas (usually an oxidizing gas as hereinafter discussed) which flows from storage (not illustrated) through a line 80 in the direction of the arrow, through a control valve 81, through a flow meter 82, and into the mixer 78. The carrier-potential controlling gas mixture flows into the diffusing zone from the mixer 78 through a manifold 85 and conduits 86. In the furnace illustrated the means 70 is duplicated on both sides of the furnace, and supplies atmosphere to two sections of the furnace. Since diffusion occurs at a relatively rapid rate it is practical to supply the potential controlling gas only to the last section, for example to the 1/6 or 1/8 of the furnace nearest the discharge end, unless work is to be cooled to a low temperature before it is discharged.

It has been found that the carbon potential of a carburizing gas is reduced by mixture therewith of an oxidizing gas such as air H_2O, or CO_2, or by dilution thereof with a substantially neutral gas. Accordingly, the apparatus described in the preceding paragraphs is operable to maintain the carbon potential of the atmosphere in the diffusing zone at any desired level below that in the carburizing zone. The apparatus can be so operated that substantially all atmosphere introduced through the means 60 into the treating zone flows toward the charge end of the furnace and is exhausted through the conduits 35 and 37. Substantially all atmosphere introduced into the diffusing zone then flows toward the discharge end of the furnace, and is exhausted through the conduits 36 and 38. The division of flow of atmosphere from the furnace chamber through the respective ends of the furnace is preferably accomplished by proper relative sizing of the exhaust conduits 37 and 38, conduit 39 being smaller when less atmosphere is to flow from the discharge end of the furnace. Positioning one of the dividing arches 57 between the carburizing zone 12 and the diffusing zone 14 assists in isolating the atmosphere in the two sections of the furnace and also assists in temperature control when, as is generally preferred when the work is to be directly quenched from the furnace, the temperature in the diffusing zone is lower than the temperature in the carburizing zone.

Under these operating conditions the carbon potential of the atmosphere introduced into the carburizing zone is adjusted to the desired value, usually between 1.00 percent and 1.40 percent, by suitable regulation of the constituents thereof. Similarly, the carbon potential of the atmosphere introduced into the diffusing zone is adjusted to the desired value, not lower than the internal carbon content of the work, and not higher than the desired surface carbon content.

The apparatus described is not limited to operation in the manner described in the preceding paragraph. It is feasible to introduce into the carburizing zone a volume of gas appreciably greater than the volume exhausted from the furnace through the conduits 35 and 37. A corresponding decrease is then made in the volume of gas introduced into the diffusing zone, and the proportion of potential controlling gas therein is increased. As a result, there is an appreciable flow of atmosphere from the carburizing zone into and through the diffusing zone; this atmosphere is diluted in the

diffusing zone with gas of carbon potential lower than desired therein. By blending of the two gases, in the diffusing zone, an atmosphere of desired carbon potential is created and maintained therein.

It is clear from the above that the apparatus can be operated to avoid appreciable mingling of the atmospheres in the carburizing and diffusing zones, or so that atmosphere from the former may flow into the latter where the desired carbon potential is created and maintained by mixture therewith of a diluting gas, preferably of a gas diluted with an oxidizing gas. However, it is preferable to avoid flow of atmosphere from the diffusing zone to the carburizing zone. Although it would be possible to operate in such way, raising the carbon potential in the carburizing zone from that required in the diffusing zone to a value within the range from 1.00 percent to 1.40 percent, as is usually preferred therein, is appreciably more difficult than effecting a corresponding decrease, as described, in the diffusing zone.

In practicing the method of the invention, it is feasible to heat ferrous metal work at a rapid rate. If sufficient provision is made for heating the charge end of the carburizing zone a substantially constant temperature can be maintained throughout this entire zone. Such temperature should be within the austenitic range of the work, because carburization is practical only at temperatures where the work being carburized is austenitic. A portion of the carburizing zone, called a carburizing region, herein, must therefore, be maintained at a temperature within the austenitic range of the work; to avoid variations in carbon potential within the carburizing region, the temperature thereof should also be approximately constant. If desired, the temperature of the charge end of the carburizing zone can be lower than the temperature of the carburizing region; the charge end then constitutes a heating region of the carburizing zone.

In general, the temperature within the diffusing zone 14 should be within the austenitic range of the work, such as 1525° F. for most carburizing grade steels, at least in the portion of the diffusing zone adjacent the carburizing zone. It is usually preferred that no temperature in the diffusing zone be higher, and most preferred that all temperatures therein be lower, than the carburizing region temperature. The diffusing zone temperature at the discharge end of the furnace is usually not higher than 1550° F., and can be as low as room temperature although preferably, it is from 1400° F. to 1550° F. from which temperature it is usually quenched. A temperature within the austenitic range of the work is required in a portion of the diffusing zone in order that carbon can diffuse from the surface of the work into the interior thereof as hereinafter described.

The improved result achieved by carburizing ferrous metal work according to the process of the invention is shown graphically in Fig. 6 of the drawings. Fig. 6 is a diagram on which is plotted carbon content of the work, expressed as percent by weight, against distance from the surface of the work. Curve I represents the condition of work carburized in the usual manner, by an atmosphere of substantially constant carbon potential, of high final potential. The curve is generally hyperbolic, approaching tangency with the abscissa at 1.20 percent carbon, and approaching tangency with a line representing 0.20 percent carbon, the carbon content of the interior of the work. Ferrous metal work having such a carbon distribution is satisfactory for many applications, but work having the carbon distribution shown by Curve II is greatly preferred. It will be noted that Curves I and II approximately intersect at about 0.65 percent carbon, 0.020 inch from the surface. This means that, so far as a user is concerned, both have the same case carbon at the effective or usable case depth of 0.045 inch. However, on the surface, Curve I shows a carbon content of 1.20 percent, while Curve II shows a carbon content of 0.76 percent.

The difference between work having a carbon distribution represented by Curve I (called "Work I," for convenience) and work having a carbon distribution represented by Curve II (called "Work II," for convenience) is highly significant to manufacturers who use ferrous metals. For example, many parts require final finishing after carburization; Work I is much more difficult to finish than is Work II because the metal that must be removed is of extremely high carbon content. Furthermore, it has been found that Work I frequently contains free carbides, which are considered to be deleterious. Also, in steels containing small amounts of boron, high carbon content is disadvantageous, while steel of a carbon content from about 0.70 percent to about 0.90 percent reacts, upon quenching, in the manner of highly alloyed steels (see S.A.E. Journal, July 1951, pages 46–52). Heretofore, so far as is known, no continuous furnace has been produced capable of carburizing ferrous metal work to provide a carbon distribution as shown by Curve II. When work is carburized in apparatus of the invention, or according to the method of the invention, a carbon distribution as shown by Curve II may be achieved.

In a preferred embodiment the method of the invention comprises passing ferrous metal work successively, first through a carburizing zone, where the surface of the work is substantially saturated with carbon at a temperature from about 1350° F. to 1800° F. by treatment with an atmosphere having a carbon potential from 1.00 percent to 1.40 percent at the saturating temperature, and then passing the work into a diffusing zone where the surface carbon of the work is reduced by diffusion at least in part at a temperature within the austenitic range of the work in an atmosphere having a lower carbon potential not substantially greater than the desired surface carbon content and not less than the percent of carbon in the interior of the work, at the temperature of diffusion. It is preferred that the carburizing gas (called a carrier gas, herein, and in the art) have approximately the following volume composition: 12 to 25 percent CO, 15 to 50 percent H_2, traces of CH_4, H_2O, and CO_2, and a balance of at least 20 percent of N_2. Most desirably, the carrier gas contains about 21 volume percent of CO, 38 volume percent of H_2, traces of methane, CO_2 and H_2O, and the balance N_2. It is sometimes desirable to enrich the carrier gas by additions of up to about 5 volume percent of a CH_4 gas. The percentage of CH_4 gas is calculated on the basis of methane, or carbon. It is also desired that gas flows be so regulated that a small positive pressure is maintained in the zones in which carburizing is accomplished according to the invention. It is preferable that carbon potential of the carrier gas be controlled by control of the dew-point thereof, other components being held substantially constant.

The extent of dilution with a neutral gas required to give a desired carbon potential in the diffusing zone can be determined as described in an application entitled "Continuous Heat Treat Furnace." The amount of an oxidizing gas required can be determined experimentally or can be calculated from known thermodynamic relations.

It is practical to accomplish carburizing according to the invention when residence times of from 2 to 14 hours in the carburizing region of the carburizing zone, and of from ½ to 6 hours in the diffusing zone are provided.

This is a division of application Serial No. 273,696, filed February 27, 1952, now abandoned.

The following example is presented solely to clarify the disclosure of the invention and is to be construed as illustrative only, and not as limiting the invention:

Example

Cold rolled steel bar stock having an interior carbon content of about 0.20 percent was carburized in a furnace substantially as illustrated in Figs. 1, 2, 3 and 4. The temperature controls were set to provide a temperature of about 1650° F. in the first ¼ of the carburizing zone, 1700° F. in the rest of the carburizing zone, which constituted the carburizing region, and temperature decreases in the direction of work travel through the diffusing zone from about 1700° F. to about 1500° F. An enriched carrier, carburizing gas atmosphere was then introduced into the carburizing zone through the means **60** and the conduits **69** at a rate of about 400 cubic feet per hour; the approximate volume composition of the carrier gas was as follows: H_2, 38 percent, CO, 21.0 percent, CO_2, trace, CH_4, 0.2 percent, dew-point +15° F., balance N_2. Natural gas, relatively pure methane, was used as an enriching gas at a rate of 30 cubic feet per hour. The carbon potential of this gas is about 1.40 percent at 1700° F. The flow of the above gas was maintained at about the indicated rate throughout carburization. A potential controlling gas was prepared by blending 400 cubic feet per hour of the above carrier gas with 15 cubic feet per hour of air, and was admitted to the diffusing zone at a rate of about 415 cubic feet per hour. The furnace pressure was slightly superatmospheric (a fraction of an inch of water) throughout the operation. Steel bar stock discharged by the furnace after residence times of about 8 hours in the carburizing zone, including 6 hours in the carburizing region, and 2 hours in the diffusing zone was found to be substantially free of deposited carbon, and to have a carbon distribution substantially as shown by Curve II of Fig. 6.

As is indicated above carbon potential can be calculated as a function of temperature, for a gas of any given composition, from thermodynamic relationships. However, in using apparatus of the invention, or in practicing the method of the invention, it is seldom possible to be certain of precise atmosphere composition at all points, particularly in the diffusing zone, even by analizing samples. Accordingly, it is usually preferable that carbon potential, particularly in the diffusing zone, be determined experimentally: namely, by determining the carbon content to which thin strips are carburized at substantial equilibrium, under a given set of conditions. If the carbon potential is higher or lower than desired in the carburizing zone, the methane in the enriched carrier gas can be lowered or raised, respectively, to make suitable compensation. If the carbon potential in the diffusing zone is higher or lower than desired, the amount of potential controlling gas can be raised or lowered, respectively, to make suitable compensation.

It is usually preferable that the carburizing region temperature be from 1550° F. to 1800° F., most desirably from 1650° F. to 1725° F.

Having described the invention, we claim:

1. A continuous method for carburizing ferrous metal work to a surface carbon content of X percent wherein X is from 0.60 percent to 1.00 percent which comprises passing the work, successively, first through a carburizing zone whose temperature is controlled to provide a substantially constant temperature within the austenitic range of the work in a carburizing region within the carburizing zone, and then through a diffusing zone whose temperature is controlled to provide a temperature within the austenitic range of the work in at least a portion of the diffusing zone, passing through the carburizing zone, substantially countercurrent to the work, an atmosphere having a carbon potential, at the temperature of the carburizing region, of from 1.00 percent to 1.40 percent, passing through the diffusing zone, in the direction of work travel, an atmosphere having a carbon potential, at the temperature of the diffusing zone, not greater than X percent and not less than the carbon content of the interior of the work, and regulating the rate of work travel to provide residence times of from 2 to 14 hours in the carburizing region of the carburizing zone, and from ½ to 6 hours in the diffusing zone.

2. A continuous method as claimed in claim 1 in which the temperatures within the carburizing zone are within the range from 1550° F. to 1800° F., and the temperatures within the diffusing zone are within the range from 1700° F. to 1200° F.

3. A continuous method of carburizing ferrous metal work to a surface carbon content of X percent which comprises passing the work, successively, first through a carburizing zone whose temperature is controlled to provide a substantially constant temperature within the austenitic range of the work in a carburizing region within the carburizing zone, and then through a diffusing zone whose temperature is controlled to provide a temperature within the austenitic range of the work in at least a portion of the diffusing zone, and no temperature higher than that in the carburizing region, passing through the carburizing zone, substantially countercurrent to the work, an atmosphere blended from a carburizing gas and not more than 5 percent of a CH_4 gas, which atmosphere has a carbon potential, at the temperature of the carburizing region, of from 1.00 percent to 1.40 percent, passing through the diffusing zone, in the direction of work travel, an atmosphere consisting of a blend of the carburizing gas with an oxidizing gas of the group consisting of H_2O, air, and CO_2, in such proportions that the carbon potential of the atmosphere, at the temperature of the diffusing zone, is not greater than X percent, and not less than the carbon content of the interior of the work, and regulating the rate of work travel to provide residence times of from 2 to 14 hours in the carburizing region of the carburizing zone, and from ½ to 6 hours in the diffusing zone.

4. A continuous method for carburizing ferrous metal work to a surface carbon content of X percent wherein X is from 0.60 percent to 1.00 percent which comprises passing the work, successively, first through a carburizing zone whose temperature is controlled to provide a substantially constant temperature within the austenitic range of the work in a carburizing region within the carburizing zone, and then through a diffusing zone whose temperature is controlled to provide a temperature within the austenitic range of the work in at least a portion of the diffusing zone, passing through the carburizing zone, substantially countercurrent to the work, an atmosphere having a carbon potential, at the temperature of the carburizing region, of from 1.00 percent to the percent for saturated austenite in the work, passing through the diffusing zone, in the direction of work travel, an atmosphere having a carbon potential, at the temperature of the diffusing zone, not greater than X percent and not less than the carbon content of the interior of the work, and regulating the rate of work travel to provide residence times of from 2 to 14 hours in the carburizing region of the carburizing zone, and from ½ to 6 hours, in the diffusing zone.

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