A method of and an apparatus for carburing steel bodies, especially a succession of steel sheet-metal bodies, which are to be processed for a given treatment time and at a given carburing temperature, although the carburing-active surface area within the carburing furnace may differ from time to time. The furnace chamber is provided with a wall composed of a sheet steel of substantially the same composition as said bodies and the through-flowing furnace atmosphere consists predominantly of carbon monoxide, hydrogen, nitrogen while small amounts of a hydrocarbon such as methane and/or propane, are added. A noncarbonaceous gas flushes the other surface of the steel wall through which carbon diffusion takes place so that the carbon content of the furnace atmosphere, as it affects the steel workpieces, is measured and the hydrocarbon content of the gas within the furnace is controlled to maintain supersaturation with carbon but at a carbon level insufficient to cause precipitation of elemental carbon upon exposed surfaces.

(1) CROSS-REFERENCE TO RELATED APPLICATION

The present application is a continuation-in-part of our application Ser. No. 36,508, filed May 12, 1970, and entitled Method of an Apparatus For Controlling the Carbon Content of Metal Bodies (now abandoned).

(2) FIELD OF THE INVENTION

The present invention relates to a method of an apparatus for carburing of carbon steel bodies in a carburing furnace and atmosphere and, more particularly, to a system for controlling the carburing atmosphere and thus the extent of carburing so as to prevent deposits of soot, carbon black and precipitated carbon from forming within the chamber and upon the workpieces.

(3) BACKGROUND OF THE INVENTION

As pointed out in the aforementioned application, the metallurgical art has long recognized the importance of controlled carburing of steel bodies to improve various physical properties including hardness, tensile strength, ductility, fatigue resistance, corrosion resistance and frictional-heat characteristics. While the steel-making process is capable of establishing a limited range of carbon contents in the steel bodies made from the raw steel, it has been found desirable to increase the carbon content at least in surface areas of workpieces composed of steel. For this reason, carburing furnaces have been proposed in which the steel body at an elevated temperature is exposed to a carbon-containing atmosphere, the carbon of which diffuses into the steel body. This system, of particular interest to the present invention, will be discussed in greater detail below.

Brief mention should be made, however, of the fact that other carburing systems have been found to be desirable because of certain problems characterizing the nature of the carburing process. For example case-hardening was considered for many years the sole effective way of bringing about uniform carburing. In this system, the high-temperature workpiece was placed in proximity to a carbon source and the entire system sealed. Diffusion of carbon into the steel body resulted and the system was opened when an equilibrium was reached. This time-consuming process had considerable advantages over other techniques including earlier attempts at diffusion carburing of steel.

The principal problem arises from the fact that a carburing process for a fixed period at a constant temperature with an atmosphere containing a given concentration of a carburing gas such as methane, propane or a similar hydrocarbon, does not always yield uniform and reproducible results because of variations in the carburing-active surface available in the furnace chamber and variations in the rate at which carbon diffuses into the steel body.

It is particularly difficult to obtain reproducible results upon a number of workpieces which may be of identical composition but of different sizes, when such workpieces are to be treated in succession in a carburing furnace of the continuously or intermittently charged type. Such furnaces are generally operated with a furnace atmosphere consisting predominantly of carbon monoxide, hydrogen and nitrogen although traces of carbon dioxide and water vapor may be present from the source of the gas. The carburing component of the furnace atmosphere, which is added to this carrier gas, is a hydrocarbon such as methane or propane, or a mixture of hydrocarbons. It is important to maintain within the furnace chamber a supersaturated atmosphere in terms of carbon, but an atmosphere which does not contain so much carbon that precipitation thereof in the form of soot or carbon black will occur. This type of control, which depends upon the rate at which carbon is diffused into the steel body, the extent of the carburing-active surface within the furnace, and other parameters of the carburing operation, has not hitherto been satisfactory and the resulting process has been uneconomical, incapable of yielding reproducible results, and unsatisfactory with respect to the uniformity of carburing.

We might mention further that it is known to measure the carbon content of a gas stream by introducing into the path of a gas stream, a membrane through which carbon diffuses and to measure the carbon content of the gas on the other side of the membrane. This technique has not, to applicants' knowledge, found application heretofore in the metal-carburing art and does not recognize the special problems in this field which derive from the different carburing-active surfaces which may be available and the differing rates of diffusion into the steel workpieces.

(4) OBJECTS OF THE INVENTION

It is the principal object of the present invention to provide an improved method of an apparatus for the carburing of steel workpieces. Another object of this invention is to provide a method of controlled carburing a succession of steel workpieces at a predetermined carburing temperature and for a predetermined individual-workpiece treatment time, whereby carbon precipitation and carbon-deposit formation within the furnace is avoided and the workpieces are uniformly carbured to the desired extent.

It is also an object of the present invention to provide a method of and an apparatus for controlling the carbon content of metal bodies which will extend the principle of the test set forth in application Ser. No. 36,508 mentioned earlier.

Still another object of the invention is to provide an improved process for modifying the carbon content of
metal bodies, to provide an improved method of carburizing fabricated steel objects composed of sheet metal and to provide an improved apparatus for the carburization of steel bodies with greater accuracy, better control and greater economy than are attainable with earlier systems and whereby the aforementioned disadvantages are obviated.

(5) SUMMARY OF THE INVENTION

These objects and others which will become apparent hereinafter are attained, in accordance with the present invention first set forth in the above-mentioned copending application by the discovery, that it is possible to control the furnace atmosphere of a throughflow furnace of the type described above and thereby obtain highly precise and reproducible diffusion when the amount of carbon-carrying gas (i.e., hydrocarbon) added to the carrier gas stream is controlled by measuring the carbon content of a flashing gas on a side of a wall of the furnace chamber through which the carbon is induced to pass at a rate substantially equal to the rate at which carbon diffuses at the workpieces.

In other words, the invention comprises a method of controlling the carburization of different steel workpieces or steel workpieces disposed in succession in the furnace chamber in varying numbers, whereby the throughflowing furnaces atmosphere, whether circulated or not, is composed primarily of carbon monoxide, hydrogen and nitrogen, the carburization temperature is held constant for all the articles and the individual-article processing time is the same so that the carburization-active surface area may vary from time to time within the furnace chamber.

The process of the present invention is characterized by the combination of the following features:

(a) The furnace chamber is separated from a test chamber by a steel-sheet diffusion membrane of substantially the same composition as the steel workpieces and preferably of identical composition, the test chamber and the surface of the diffusion wall thereof being well in contact with a noncarbonaceous carrier gas (i.e., oxygen or nitrogen) containing a minor proportion of at least one hydrocarbon gas (carburizing-carbon carrier), preferably methane or propane or both, adapted to diffuse carbon into carburization-active surfaces of the workpieces;

(b) Maintaining the carburization temperature in the furnace chamber substantially constant for the successive workpieces and controlling the charging thereof so that the carburization time for the individual articles is also substantially constant;

(c) Continuously measuring, over the interval in which the carburization-active surface area may vary within the furnace chamber, the rate of carburization of the articles in the furnace chamber as a result of abstraction of carbon from the atmosphere, by permitting carbon diffusion from the carbon environment through a wall of the furnace chamber composed of the aforementioned steel-sheet diffusion membrane of substantially the same composition as that of the articles or workpieces, flushing the surface of the diffusion membrane (steel sheet) turned away from the furnace chamber with a noncarbonaceous gas stream (test gas), and detecting the carbon content of the test gas stream after flushing of the wall therewith;

(d) Controlling the addition of the hydrocarbon to the carrier gas entering the furnace in accordance with the carbon content of the test gas stream to maintain a predetermined available-carbon proportion within the furnace in spite of variations in the rate at which carbon is taken up by said bodies.

It has been observed, as noted above, that the preferred carburization state is one in which the furnace atmosphere is supersaturated in carbon but the atmosphere does not contain sufficient carbon to induce precipitation or deposition thereof. Surprisingly, it has been found that the present system of measuring the carbon passing through a diffusion-permeable partition, enables adjustment of the carbon content of the furnace atmosphere to maintain the desired state of supersaturation, prevent carbon deposition and also ensure effective carburization of the workpieces because the partition and the workpieces are composed of the same metal.

According to the present invention and, as described in the aforementioned copending application, the furnace chamber is provided with a sheet-metal partition of the same composition as the steel body or workpiece to be treated and preferably of the same thickness through at least the depth to which carburization is to be carried out, the carbon diffusing through this partition from the main furnace chamber into the test chamber and being carried away to the measuring instrument. The carbon content in this chamber varies in a rate which is related to the rate of change of the carbon content within the furnace by a factor which depends upon the rate of diffusion of the carbon into the workpieces and thus through the partition. The diffusion-permeable partition, forming a wall of the furnace or heat-treatment chamber, preferably forms part of a low-volume duct traversed by the noncarbonaceous gas at a predetermined (constant) flow rate, concentration and pressure, which entrains the diffused carbon (usually in the form of carbon-carrying gas) to the measuring instrument which can indicate directly the rate of carbon diffusion into the steel body, the variations of the carbon content of the furnace atmosphere, etc., and can automatically adjust the carbon content of the atmosphere accordingly. The measurement accuracy may be improved by constituting the diffusion membrane or partition as a small-diameter tube of a thickness corresponding to the thickness of the sheet metal from which the workpieces are constituted, by disposing the partition close to the steel bodies subjected to the treatment, and by proper selection of the carrier gas which may be nitrogen, hydrogen or a mixture thereof in the test cell.

It is important to note that the present invention does not merely involve the diversion of a portion of the at-
mosphere from the main body of gas therein for the purpose of determining the carbon content thereof but rather requires a diffusion of the gas through a membrane of the same material as the metal stock to be treated so that change of the carbon content of the atmosphere will be reflected in the test cell or measurement cell only in accordance with the extent to which this change in carbon concentration involves a change in the diffusion of carbon into the steel workpieces.

Best results have been achieved with a furnace atmosphere consisting essentially of 40% by volume hydrogen, 20% by volume carbon monoxide and 40% by volume nitrogen, although traces of carbon dioxide and water vapor may be present. The carbon monoxide and carbon dioxide of the carrier gas do not contribute to the available carbon or carburization which is carried out at a temperature upwards of, say, 900° C. At this temperature, the methane and/or propane may be activated by free-radical reactions or otherwise and eventually yields the carbon which penetrates the steel body. The carburization medium preferably consists of 1% by volume propane and 8% by volume methane.

(6) DESCRIPTION OF THE DRAWING

The above and other objects, features and advantages of the present invention will become more readily apparent from the following description reference being made to the accompanying drawing, the sole figure of which is a vertical cross-sectional view through an apparatus for carrying out the process of the present invention, portions of the apparatus being illustrated diagrammatically.

(7) SPECIFIC DESCRIPTION

The pot-shaped heat-treatment furnace 1 illustrated in the drawing comprises a generally cylindrical upright wall 1a closed at the bottom 1b and formed with a flange 1c surrounding a mouth 1d through which steel objects can be introduced for treatment.

For the purposes of the present application and for illustration in accordance with the following specific example, the steel objects are pots, pans, coffeepots and like cooking and serving utensils composed of steel which may be charged into the furnace intermittently so that the carburization-active surface area varies from time to time. Although an intermittent treatment system has been illustrated, it should be noted that the invention is also applicable to continuous furnaces as well. It is only essential that the temperature and treatment time for the individual articles be the same and the carburization atmosphere be controlled as will be apparent hereinafter.

The interior of the furnace is provided with a grate 2, subdividing the furnace into a lower chamber 1e in which combustion may be sustained to produce a temperature of about 900° C. The upper chamber 1f constitutes the treatment chamber and receives the workpieces 3. A cover 4 is sealingly connected to the flange 1c at the mouth of the furnace and adjacent the mouth, there is provided a fitting 5g for the removal of waste gases.

A carburizing carrier gas of the composition set forth above, i.e., predominately consisting of carbon monoxide, hydrogen and nitrogen, is circulated through the upper chamber 1f and the carburizing carbon level may be established by a valve 5e which controls the feed of methane and/or propane to the carburizing gas. A valve 5b is provided to control the throughflow of the carrier gases.

The carrier or furnace chamber or tube 6 is partitioned by a steel tube 6a of the same composition as the workpieces and of the same thickness, to define a compartment or test cell 6c through which a test carrier gas is induced to flow. Preferably the tube 6 is upright and is connected at its upper and lower ends to a supply tube 6a of U-shaped outlet tube 6b, respectively.

A fitting of the tube 6a external of the furnace 1 is connected to a source of the test gas which may be a mixture of nitrogen or hydrogen as noted earlier. Downstream of line 6b, there is provided a contact oven or catalyst chamber 7 of conventional design, capable of converting all of the carbon of this latter gas stream to carbon dioxide. The carbon dioxide is removed via conventional meter 8 and the output thereof is applied to a servocontrol 8a which has a reference input representing the desired carbon level in the furnace atmosphere. Valve 8a is automatically adjusted by the output of the servocontrol 8a to adjust the methane flow accordingly.

Diffusion of carbon into the workpieces 3 occurs in chamber 1f in the conventional manner and is consequent with diffusion through the tube 6, the diffused gases being entrained by the inert gas stream, catalytically or otherwise converted to carbon dioxide, measured at 8 and producing a feedback signal to operate the valve 8a via the servocontrol 8a.

(8) SPECIFIC EXAMPLE

Using the apparatus illustrated in the drawing, steel cooking utensils are treated in succession and with various carburizing-active surface areas, the utensils being composed of 85.0% iron, 14.5% silicon, 0.1% carbon and 0.35% manganese to a surface carbon content of 0.85% all by weight. For all of the successive treatments, the temperature was maintained at 900° C. and the treatment time was two hours and 52 minutes, regardless of the shape and size of the workpieces.

The carrier gas consisted of 20% carbon monoxide, 40% hydrogen and 40% nitrogen, to which were added 1% propane and 8% methane, all by volume.

The tube 6c was composed of the same steel, had a wall thickness of 1.1 mm., an axial length of 19 cm., and an outer diameter of 20.7 mm. The steel tube was held between a ceramic (THERMAX) tubes and 50 to 60 liters per hour (STP) of nitrogen and hydrogen (10% by volume H₂ and 90% by volume N₂) with a dewpoint of 28° C. was used to flush the tube. Using the method and apparatus described in the prior application and in Acta Metallurgica, vol. 1, September 1953, the carbon diffused through the tube and in the flushing gas was catalytically converted to carbon dioxide and the proportion thereof was measured.

The measurement was used to control the methane and propane content of the furnace gas which was passed through the chamber in a volume of 18 liters over the treatment period. The utensils, coffeepots of cylindrical configuration with a height of 25 cm., a wall thickness of 3 mm. and an outer diameter of 15 cm., were reproducibly carburized regardless of the number of them accumulated in the furnace. The carbon content of the furnace atmosphere could be maintained at supersaturation without precipitation or deposition of elemental carbon.

We claim:
1. A method of carburizing a plurality of steel articles, comprising the steps of:
   (a) charging a carburizing furnace chamber with a succession of said steel articles;
   (b) passing through said furnace chamber and into contact with the steel articles successively charged into same, at a substantially constant volume flow rate, a carrier gas consisting predominantly of carbon monoxide, hydrogen and nitrogen and containing a minor proportion of at least one hydrocarbon gas adapted to diffuse carbon into carburization-active surfaces of said steel articles;
   (c) maintaining the carburization temperature in said furnace and a treatment time for the successive articles which is substantially constant;
   (d) continuously measuring the rate of carburization of said articles and the rate of abstraction of carbon from said carrier gas in said furnace by:
      providing said furnace chamber with a wall composed of steel of the identical composition to
and the same thickness as the steel of said articles,
permitting carbon diffusion from the furnace chamber through said wall thereof composed of steel of the same composition and thickness as that of said articles,
flushing a surface of said wall turned away from said chamber with a noncarbonaceous gas stream whereby carbon from the environment in said chamber diffuses through said wall substantially at the rate at which carbon diffuses into said articles and is entrained by said flushing gas stream,
detecting the carbon content of said gas stream after flushing of said wall therewith; and
(e) controlling the concentration of the hydrocarbon in the carrier gas introduced into said furnace in accordance with the carbon content of said gas stream.

2. The method defined in claim 1 wherein the addition of said hydrocarbon to said carrier gas is controlled in accordance with the carbon content of said gas stream to maintain carbon supersaturation in said carrier gas but preclude carbon deposition in said chamber.

3. The method defined in claim 2 wherein said hydrocarbon is selected from the group which consists of methane, propane and mixtures thereof.

4. The method defined in claim 3 wherein the carrier gas consists substantially of 20% by volume carbon monoxide, 40% by volume hydrogen and 40% by volume nitrogen and substantially 8% by volume methane and substantially 1% by volume propane are added to said carrier gas.

5. The method defined in claim 4 wherein said carbon content of said gas stream is detected by catalytically converting carbon in said gas stream to carbon dioxide, and measuring the concentration of said carbon dioxide in said gas stream.

6. The method defined in claim 5 wherein said noncarbonaceous gas stream is of constant composition and flow rate for said succession of articles.

7. The method defined in claim 6 wherein said temperature is above substantially 900° C. and said articles are carburized for a period in excess of two hours.

8. An apparatus for the carburization of steel articles, comprising:
(a) a carburizing furnace having a furnace chamber adapted to accommodate articles composed of steel;
(b) means for passing a carrier gas through said chamber;
(c) means for heating the articles in said chamber to a carburizing temperature;
(d) means for adding a selected proportion of a hydrocarbon adapted to carburize said articles at said temperature to said carrier gas;
(e) a tube of a steel composition identical to that of said articles disposed in said chamber and of the same wall thickness;
(f) means for passing a noncarbonaceous flushing gas through said tube;
(g) means for detecting the concentration of carbon in said flushing gas; and
(h) control means responsive to said means for detecting the carbon concentration in said flushing gas for automatically regulating said means for adding said hydrocarbon to said carrier gas.

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