June 6, 1939. J. W. HARSCH 2,161,162

METHOD OF CARBURIZING

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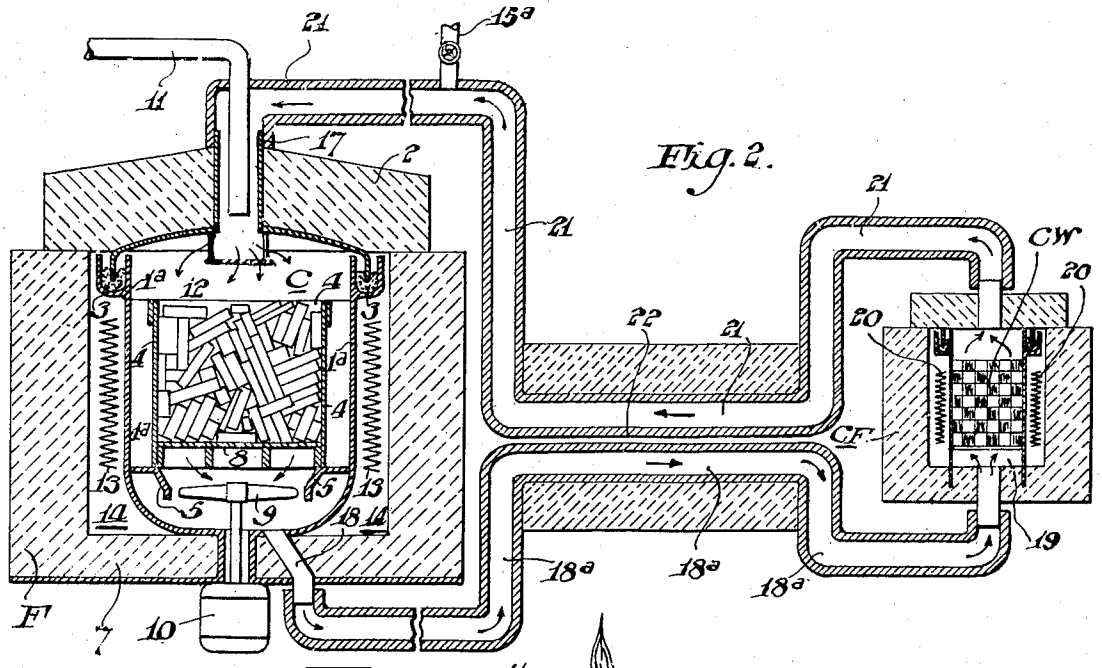


Fig. 2.

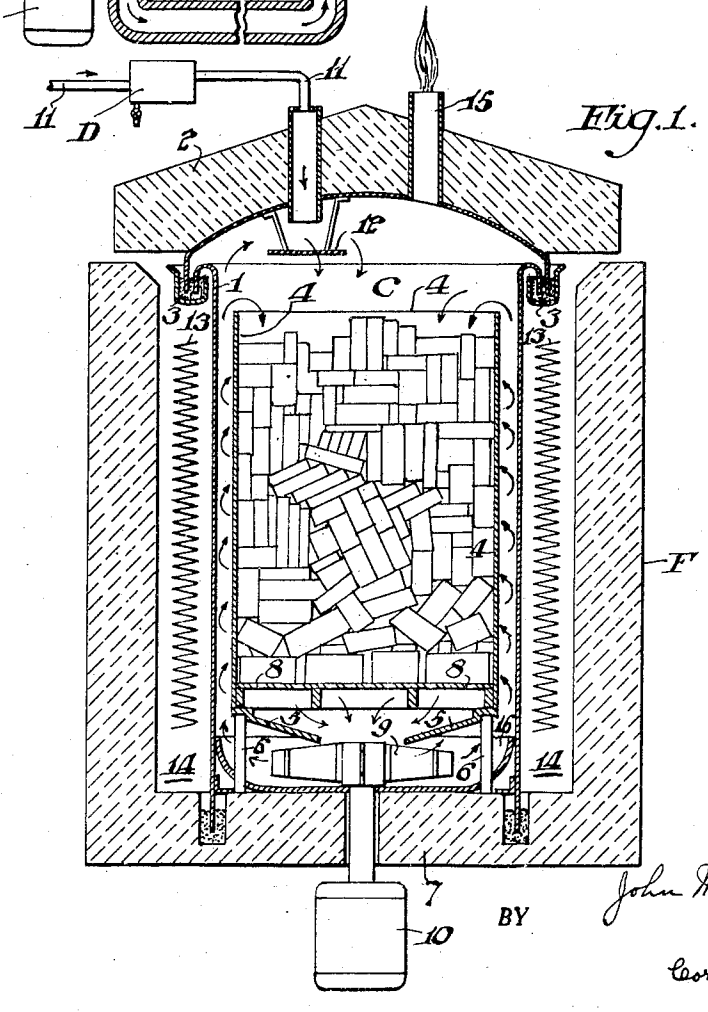


Fig. 1.

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June 6, 1939. J. W. HARSCH 2,161,162

METHOD OF CARBURIZING

Filed Jan. 6, 1938 5 Sheets-Sheet 2

Fig. 3.

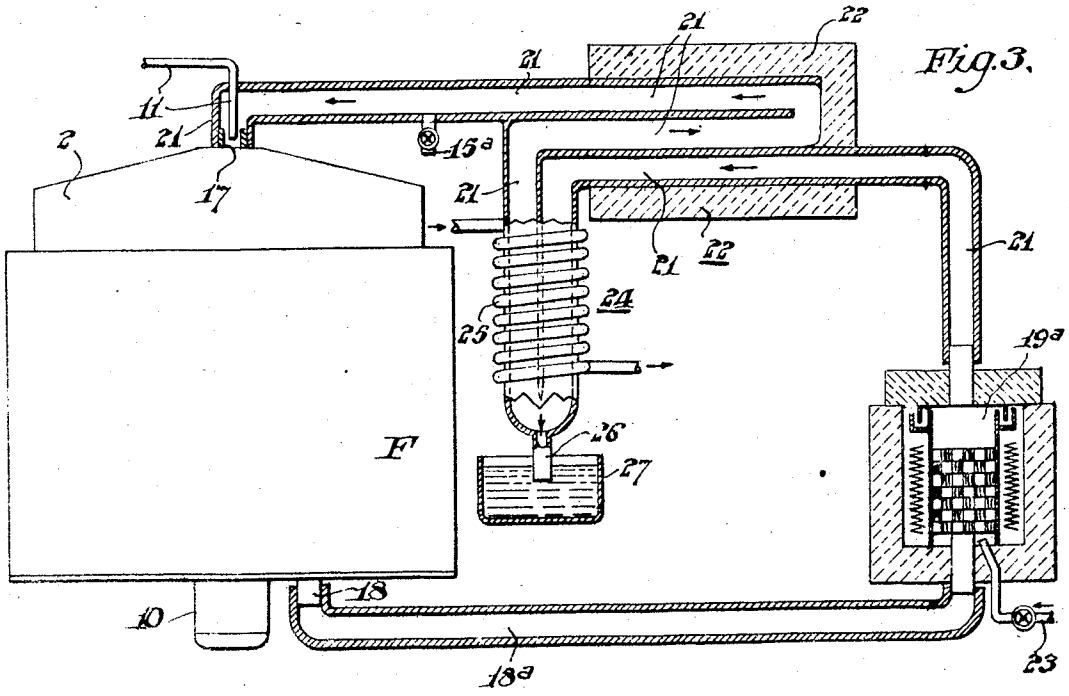
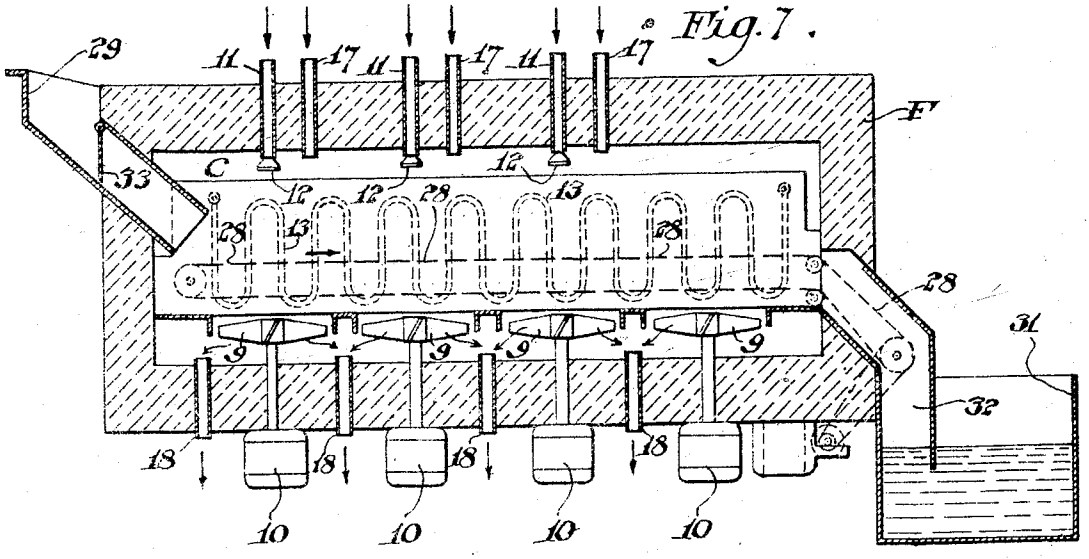


Fig. 7.



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June 6, 1939. J. W. HARSCH 2,161,162

METHOD OF CARBURIZING

Filed Jan. 6, 1938 5 Sheets-Sheet 3

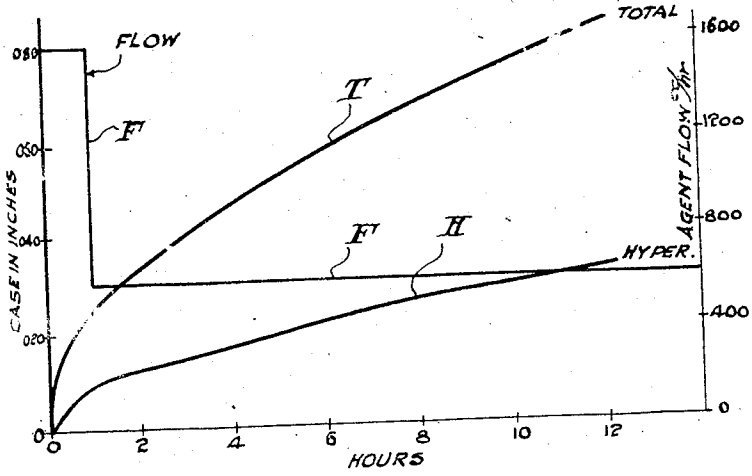


Fig. 4.

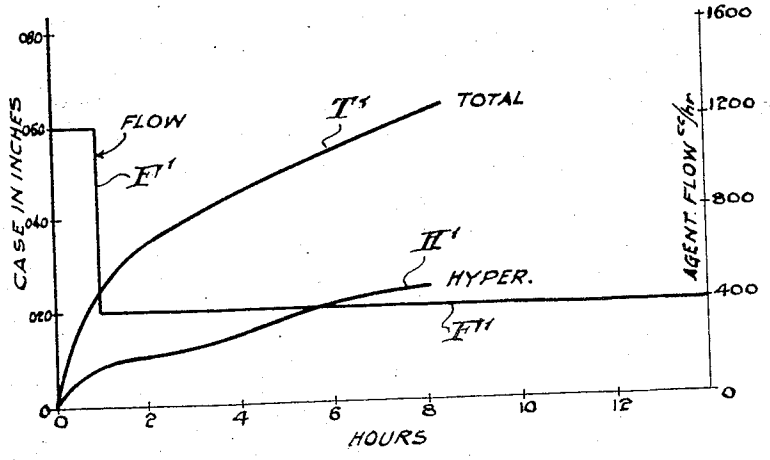


Fig. 5.

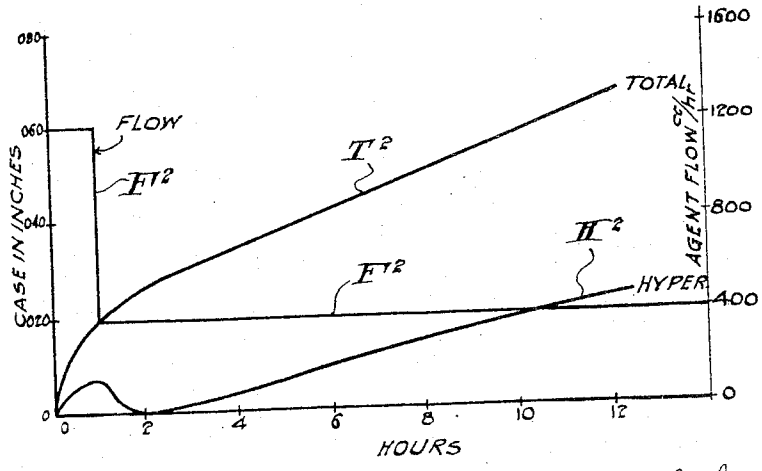


Fig. 6.

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METHOD OF CARBURIZING

Filed Jan. 6, 1938 5 Sheets-Sheet 4

Fig. 8.

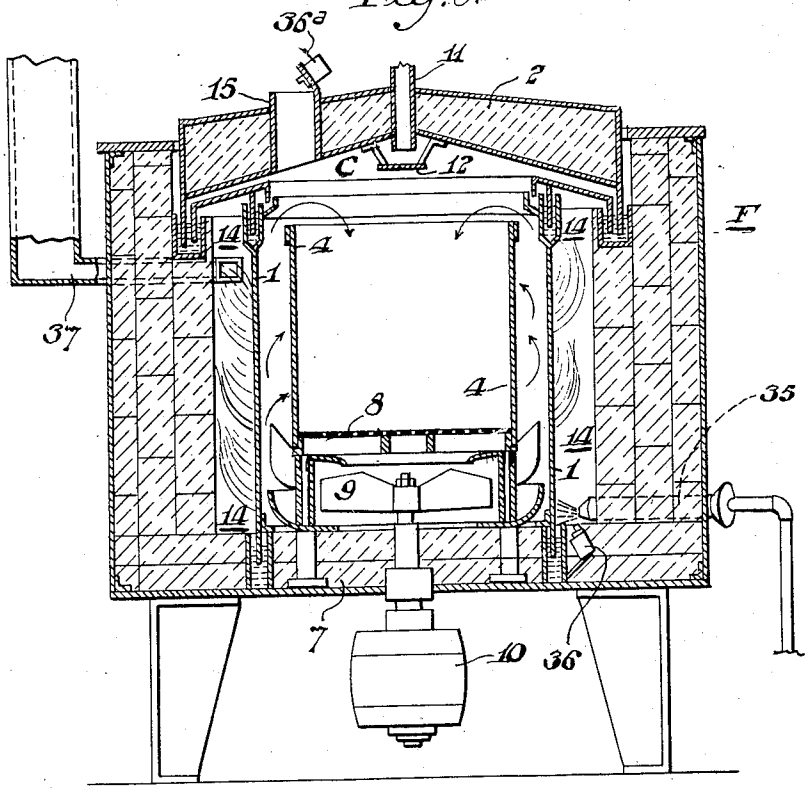
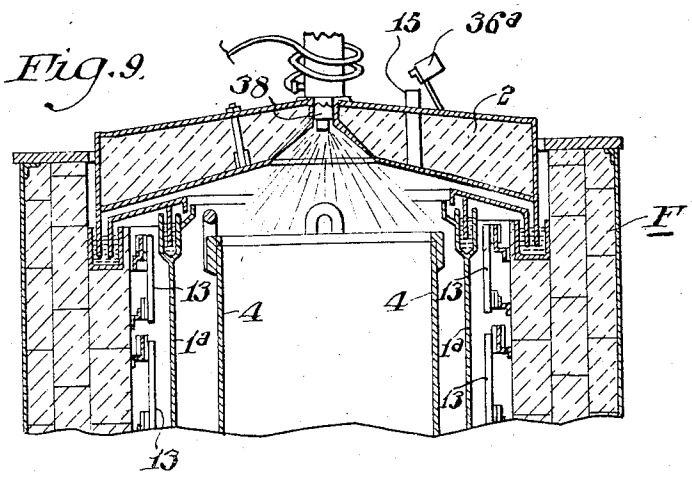


Fig. 9.



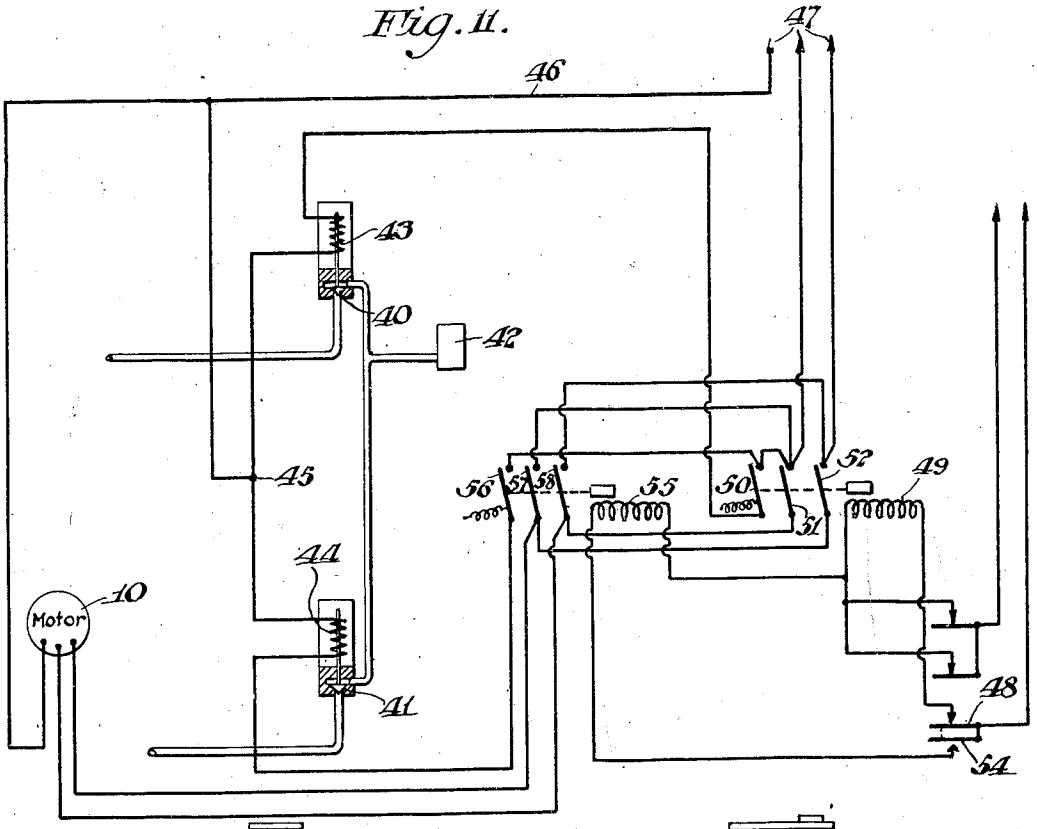
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June 6, 1939. J. W. HARSCH 2,161,162

METHOD OF CARBURIZING

Filed Jan. 6, 1938 5 Sheets-Sheet 5

Fig. 11.



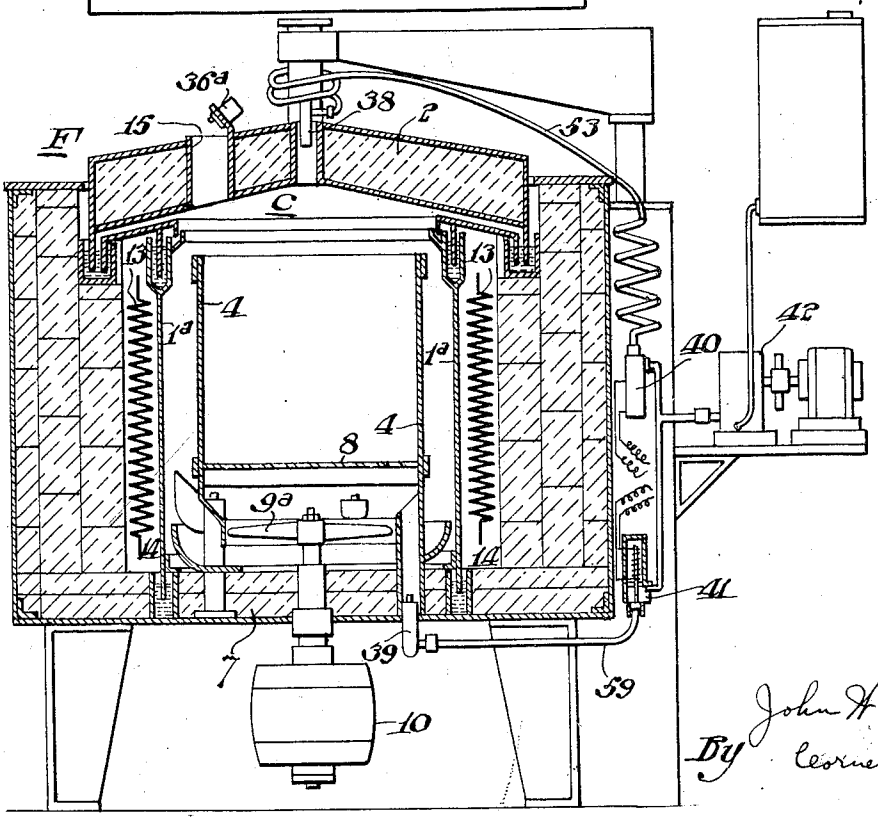


Fig. 10.

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Patented June 6, 1939

2,161,162

UNITED STATES PATENT OFFICE

2,161,162

METHOD OF CARBURIZING

John W. Harsch, Gwynedd, Pa., assignor to Leeds and Northrup Company, Philadelphia, Pa., a corporation of Pennsylvania

Application January 6, 1938, Serial No. 183,618

14 Claims. (Cl. 148—17)

My invention relates to methods of producing diffusion alloy cases upon steels or alloy steels, herein generically termed steels, by subjecting them to carburizing agents, and relates particularly to control of the nature of the atmosphere of carburizing furnaces and to control of the carburizing and associated reactions.

It is an object of my invention to procure, especially in the earlier part of as well as throughout a carburizing run, maximum rate and maximum uniformity of carburization throughout the load, to the end of materially improving the product and reducing the time required for and cost of carburization.

In accordance with a broad aspect of my invention a carburizing agent, suitable carbonaceous material in liquid, vapor or gaseous phase and yielding the ultimate carburizing reagent or reagents, is introduced into the vehicle or carrier gas passed through or in contact with the load throughout, and preferably recirculated, at a particular region or point in its path, to wit, in advance of but closely adjacent the first contact of the vehicle gas with the load.

In accordance with another aspect of my invention, the surface layer of the steel is during the first part of the run saturated with carbon in minimum time throughout the load, by an agent introduced into the vehicle or carrier gas, slightly in advance of or closely adjacent its first contact with the load, and yielding carbonaceous reagent product or products having highest carburizing potential with respect to the steel; and after such first portion of the run for at least a part of or for the whole of the remainder of the run the carburizing potential is maintained uniform throughout the load to maintain the aforesaid saturation.

In accord with an aspect of my invention, there is applied throughout the load the products of primary cracking or dissociation of a suitable agent having the effect of breaking the bond or bonds between carbon atoms of molecules of the agent, such reagent product or products having highly preferential and high carburizing potential masking or preponderating over or substantially excluding carburizing effects of products of such secondary cracking or dissociation of said agent as may take place and characterized by the breaking of bonds between carbon and hydrogen atoms.

In accordance with my invention, broadly and without limitation to other of the aspects of my invention herein described, it is the nascent products of primary cracking or dissociation of the agent introduced into the vehicle gas which are effective, because preferentially effective in carburizing, substantially to the exclusion of effects of the products of secondary cracking or dissociation for which the steel has markedly lower preference, or in any event the primary products so preponderate in their effects over those of the products of secondary cracking or dissociation that the latter do not of themselves effect substantial carburization of the load, so leaving the load preferentially to respond by way of carburization thereof substantially exclusively to the products of the primary cracking or dissociation; and so substantially avoiding or reducing in the carburized case carburizing effects other than those due to the products of primary cracking or dissociation.

A further aspect of my invention resides in control of the rate of supply to the vehicle gas of the carburizing agent such that the aforesaid primary dissociation thereof is substantially completed within and throughout the load itself, in substantial prevention or elimination of deposit of carbon upon the work in the form of soot resulting from employment of excess reagent above that sufficient only to retain the aforesaid saturation at the surface of the work, and also in prevention of primary cracking or dissociation of the agent external to the work chamber, and further in prevention, as when the vehicle gas is repeatedly circulated through the work chamber, of formation of soot transportable in the gas to the work with deposit thereon.

In accordance with my invention, into the vehicle gas, whether it be non-carburizing or at most of low or insubstantial carburizing power, there is introduced, at a point or region closely adjacent its entry into the work or load, for the production of a nascent carburizing product, a carburizing agent in liquid, gaseous or vapor phase, of suitable composition, to wit, a compound or compounds of carbon and hydrogen or of carbon hydrogen and oxygen, characterized, however, by the fact that in either case the molecular structure comprises atoms of carbon having carbon to carbon bond or bonds, whereby, during passage of the vehicle gas and agent through the load while at temperature at least as high as that essential to carburizing action, the carburizing agent so introduced is subjected throughout its passage through the load, and preferably not beyond the load, and at the surface of the work throughout the load, to primary cracking or dissociation of the molecules of the carburizing agent having the effect of rupturing

the aforesaid carbon to carbon bond or bonds, and yielding throughout its passage with the vehicle gas through the load a nascent carburizing reagent of high or maximum carburizing power or potential, and concentration, such that throughout the load there prevails maximum rate of carburization having the effect of building up, at the earliest possible moment at carburizing temperature, carbon-saturation of the surface layer of the steel; otherwise stated, establishing at earliest possible moment maximum slope of the depth-time characteristic or maximum rate of penetration which results from establishment at the earliest possible moment of high surface saturation conducive to maximum possible inward gradient.

Further in accordance with my invention, the carrier gas, after having once passed through the load, is, before reentry into the load, subjected, in the presence of a catalyst if desired, to temperature, preferably or usually higher than that obtaining in the load, to effect dissociation or cracking of residual carbonaceous compounds, including products of secondary dissociation occurring within the load, usually principally methane, substantially to prevent upon reentry of the vehicle gas into the load zone presence therein of carburizing compounds, or excess carbonaceous material which within the load would otherwise cause deposition of soot therein or would yield atomic hydrogen tending partially to decarburize or lower the desired concentration of carbon in the steel below the aforesaid desired saturation point; and in accordance with a further aspect of my invention in this regard, the currents of the vehicle gas to and return from the region of aforesaid cracking external to the load are disposed in heat exchange relation with each other.

Further in accordance with my invention, the vehicle gas, after having once passed through the load, may be subjected to partial or incomplete combustion reaction yielding, by the conversion of the carbonaceous material, carbon monoxide, hydrogen and nitrogen, which the vehicle gas returned to the load then comprises, and having the effect of preventing presence in the load of hydrogen in nascent or atomic state, of preventing deposit of soot upon the work, and of preventing entry into the load zone of products having undesirable carburizing effects; and the currents of the vehicle gas to and from the zone of incomplete combustion may be disposed in heat exchange relation with each other.

In accordance with another aspect of my invention economically and rapidly to obtain a desired composition and depth of case, the rate of feed of carburizing agent is high or maximum at the beginning of the run to procure the aforesaid saturation, and is thereafter during the remainder of the run decreased, or the feed of the agent discontinued, in accordance with a predetermined program, progressively or in one or more steps.

Further in accordance with my invention, when provision is made for reversing the direction of circulation of the vehicle gas, whatever may be the character of carburizing agent employed, the region or point of introduction thereinto of the carburizing agent is also, and preferably substantially concurrently changed and, specifically, to the end that for both directions of circulation the carburizing agent is introduced into the vehicle gas closely adjacent its entrance into the work.

For an understanding of my invention, reference is to be had to the accompanying drawings in which:

Fig. 1 in section illustrates a carburizing furnace suited to perform my method;

Figs. 2 and 3 illustrate other modified forms of carburizing systems;

Figs. 4, 5 and 6 are performance curves referred to in the subsequent description;

Fig. 7 in section illustrates a continuous type of furnace adapted for performance of my method of carburizing;

Fig. 8 illustrates a gas-fired carburizing furnace utilizing the invention;

Fig. 9 shows a furnace similar to those of preceding figures but utilizing a specifically different means for introduction of the carburizing agent;

Fig. 10 illustrates a carburizing furnace providing for reversal of the circulation of the carburizing atmosphere and of the point of introduction of the carburizing agent;

Fig. 11 is a wiring diagram of a control system for the carburizing furnace of Fig. 10.

Referring to furnace F of Fig. 1, the load comprising one or more work pieces to be carburized, is disposed in a reaction chamber C defined by the retort 1, the cover 2, and the seal 3 between the cover and the retort. For convenience in loading and unloading, the work or load is carried by the removable basket 4 which rests upon a suitable member 5 supported by standards 6 extending upwardly within the retort from the base 7 of the furnace F. When the load comprises a multiplicity of pieces they may be disposed haphazardly in the basket or arranged in predetermined relation by perforated platforms or screens. For brevity, in the description and claims, the term "load" shall be understood to comprehend a group or batch of pieces, or a single piece. Below the perforated plate or grid 8 forming the bottom of basket 4 is the fan 9, driven by motor 10, external to the furnace, forcibly to circulate through the load hot vehicle gases which serve as a carrier for the carburizing components of the furnace atmosphere. The carburizing agent in liquid, gaseous or vapor phase is supplied to the reaction chamber C by the inlet pipe 11 which, or an extension thereof, projects through cover 2 directly above the load in the work basket. The hot vehicle gases swirling about in the space below the cover and above the work there entrain and distribute the freshly introduced agent and quickly bring it to dissociation temperature.

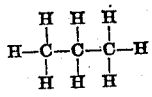
To prevent impingement upon the work or load of unvaporized carburizing liquid when the carburizing agent is introduced into the furnace in liquid phase, there is preferably provided a plate 12, or equivalent, disposed below the exit end of the inlet pipe 11 and heated by the aforesaid vehicle gases to a temperature sufficiently high to effect substantially immediate vaporization of any of the introduced agent not vaporized by the vehicle gases before it contacts the plate.

The work pieces are heated to carburizing temperature, usually about 1700° F., in any suitable manner, for example by electrically heated resistors 13 disposed in the heating chamber 14 which surrounds the retort 1. The chamber 14 may, of course, be heated by other means, for example as hereinafter illustrated, by combustion of liquid or gaseous fuel and air injected into the heating chamber by one or more suitable nozzles.

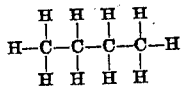
The carburizing agent introduced into the top of the reaction chamber C above the work, as near thereto as possible without causing a cold spot, is there immediately entrained by the hot vehicle gases, which under desirable conditions of operation hereinafter described, have little or no tendency or ability to exchange carbon with the work or with the dissociation products of the carburizing agent, and quickly raised thereby to temperature effective to cause cracking or dissociation thereof; the mixture of carburizing agent and the hot vehicle gas is immediately drawn downwardly through the load at suitably high velocity by fan 9.

The carburizing agent supplied to pipe 11 may be any carbonaceous compound (or compounds) suitable for at least some of the present purposes; and preferably is a hydro-carbon compound (or compounds), for example butane, propane, ethane, dipentene, turpentine, liquid or gaseous at ordinary room temperatures and pressures and commercially available, or any suitable compound of oxygen, hydrogen and oxygen, for example furfural, fusel oil, diethyleneglycol, diethyleneglycolmonoethylether, or a suitable mixture of such compounds; and all of which have molecular structures characterized by one or more carbon to carbon bonds, and therefore having two or more mutually bonded carbon atoms:

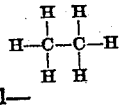
For example, the molecular formula of propane is—



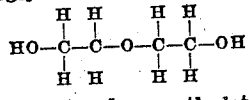
Of butane—



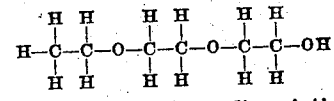
Of ethane—



Of diethyleneglycol—



And of diethyleneglycolmonoethylether—



The primary cracking or dissociation of any of such carburizing agents, begins almost immediately upon its admixture with the vehicle gases to yield an atmosphere having high carburizing power or high carbon potential with respect to the steel of the load.

The point of introduction of the carburizing agent into the vehicle gas is of great practical importance. It should be introduced into the carrier gas at such region or point that the agent first reaches cracking temperature closely adjacent to or in contact with the work, where cracking immediately begins. The distance between the place of introduction of the carbonaceous material into the vehicle gas and first contact thereof with the work and the velocity of the vehicle gas are such that there are not formed at substantial rate or in substantial quantity products of cracking or dissociation of the carbonaceous material prior to its first contact with the load.

By introducing the carburizing agent into the vehicle gas just before its entrance into the load, the primary cracking or dissociation, characterized by rupture of carbon to carbon bonds of molecules of the agent or its dissociation products, does not begin appreciably before contact with the work or load; consequently soot due to premature cracking or dissociation is not deposited upon the load surface or in the voids between the work pieces. The zone of primary cracking should substantially correspond with and comprehend the zone in which the load is disposed; more particularly the primary cracking zone should be as long as, and preferably not substantially longer than, in the direction of travel of the vehicle gas at and through the work, the length of the load; and at least as great in cross-section as the cross-section of the zone or volume occupied by the load. If primary cracking of the agent begins appreciably before the agent reaches the work, soot deposits form thereon, particularly on the gas-entrance side of the load, to the detriment of uniformity of carburization. If primary cracking continues appreciably beyond the load, soot is formed, which, if the vehicle gas is recirculated, as specifically shown in the furnace of Fig. 1, is transported by the vehicle gas and deposited on the load surface or in the voids between the work pieces; if the primary cracking terminates before exit of the carburizing agent or products thereof from the load, carburization of the steel proceeds at much lower rate near the exit end of the load, and since all parts of the load are under treatment for the same length of time, the case will be inferior at that region because subjected to the products of secondary cracking, for example such as are characterized by rupture of carbon to hydrogen bonds.

In accord with prior practices, the atmosphere in contact with the load has been a heterogeneous mixture of the products of both primary and secondary dissociation; the ratio to each other of the quantities of the primary and secondary cracking products not only was not fixed or constant, and varied from time to time, but also varied as between different parts of the load. The carburizing effects upon the steel likewise were heterogeneous, in part due to products of primary cracking, and in substantial, and usually major, part due to products of secondary cracking.

In contrast, by my invention carburizing effects of products of secondary cracking with the load are minimized or avoided; on the contrary the atmosphere utilized in accord with the present invention is of maximum carburizing power afforded and obtainable substantially only by the products of primary cracking to the substantial exclusion of products of secondary cracking; since secondary cracking does not to substantial extent occur within the load zone, products thereof are not there present, and since products of secondary cracking occurring beyond the load are rendered non-carburizing, undesired carburizing effects incident to presence of those products in the load are avoided.

In any event to whatever extent secondary cracking of the fresh agent occurs as it sweeps through the load, the carburizing effects of the products of secondary cracking are swamped or masked throughout the load by the materially preponderating carburizing effects of the products of primary cracking of the agent.

When the agent is introduced as herein described to insure primary cracking, and substantially only primary cracking, throughout its con-

tact with the work and not substantially before contact therewith, the characteristic desirable conditions of high and uniform carburizing power or high maximum carburizing potential of the treating atmosphere throughout the load obtain throughout relatively wide range of rates of feed of the carburizing agent. The optimum rate of feed for a given furnace may be determined by a few trials. The rate of feed should not be so high that the resultant nascent carbon shall exceed in quantity that which the steel is capable of absorbing, nor so high that there occurs deposits of soot in the load zone sufficient materially to prevent absorption by the steel of nascent carbon as rapidly as produced by the primary cracking reaction. Nor should the rate of feed be so low that carburizing proceeds at lower rate on the work pieces adjacent the bottom of the load because of ability of the steel to absorb nascent carbon more rapidly than it is there produced.

With a furnace of the type shown in Fig. 1, using a work basket or about 18 inches internal depth and 15 inches internal diameter, a fan speed of about 1800 revolutions per minute for circulating the carrier gas having swirling action, and basket fully loaded with haphazardly arranged pieces of steel about 6 inches long, 1 inch diameter, the rate of feed of liquid carburizing agent, specifically fusel oil, may throughout different runs be anywhere within a range of 200 to 400 cubic centimeters per hour (cc./hr.) without appreciable effect upon the uniformity of the case, the total depth of case, or the composition of the case, for all parts of the load; at a rate of feed of about 500 cubic centimeters per hour the case is nonuniform, particularly on work pieces near the top of the load; at 100 cubic centimeters per hour, the case on the work pieces near the bottom of the load is much less in total depth and much less in hypereutectoid content than the case on the work pieces at or near the top of the load.

As typical of results consistently obtainable, a four hour run at 1700° F., with agent feed 400 cc./hr. throughout the run, fan speed 1750 revolutions per minute, yielded a case whose total depth was .045", hypereutectoid depth, .012", with maximum variation in either total or hypereutectoid depth throughout the load of not more than .002".

When, in contrast with the present invention, the carburizing agent is introduced so that the atmosphere with the newly added agent strikes the fan, then passes around the hot work basket and into repeated contact with the hot sides of the retort before engaging and passing through the load, there is marked lack of uniformity between the case formed on the upper work pieces and the case formed on the lower work pieces of the load. The case on the lower work pieces is of inferior total depth and of inferior hypereutectoid content. With this inferior mode of feed, the primary cracking reaction of freshly introduced agent so far progresses before the treating atmosphere reaches the bottom of the load that the principal active carburizing gas there effective is methane, a product of secondary dissociation, whose carbon potential with respect to the steel is low compared to that of the products of the primary cracking reactions. Increase or decrease in the rate of supply of the carburizing agent does not remedy the situation; the former increases soot deposits and causes even greater variation in composition of the case throughout the load, and the latter slows down the rate of case formation without procuring uniformity.

Thus when primary dissociation of the carburizing agent begins appreciably before or too far in advance of contact with the load, there is no rate of feed of carburizing agent which affords high rate of case formation with concurrent uniformity of case formation throughout the load.

The significant difference between results obtained when the agent, whether or not of the herein specified preferred types, is introduced in accord with the present invention and when introduced in accord with prior practice, is exemplified by Tables A and B which follow. All conditions, including character of agent, rate of feed of agent, duration of run, direction of circulation of vehicle gas, character of load, etc., were identical, except that for Table A the carburizing agent was introduced, as in Fig. 1, into the vehicle gas just before its contact with the load, whereas for Table B the carburizing agent was injected against a target positioned above the fan 9, Fig. 1, and below the grid 8, so that the fresh agent before reaching the work passed through the fan and then upwardly outside of the basket 4.

Table A

Location of specimen	Case—depth	
	Hypereutectoid	Total
Top	.012	.044
Center	.012	.045
Bottom	.011	.042

Table B

Location of specimen	Case—depth	
	Hypereutectoid	Total
Top	.012	.042
Center	.006	.036
Bottom	.005	.036

When, in accord with my invention, the fresh carburizing agent is introduced into the vehicle gases just before they enter the load, the carburizing power of the resulting atmosphere is, while in contact with the load, high, and uniform throughout the load. The secondary cracking reactions, occurring after the agent has been carried through the load by the vehicle gas and before fresh carburizing agent is entrained adjacent the load, as above its top, e. g., Fig. 1, occur while the atmosphere is out of contact with the work pieces and therefore their product does not reduce the carbon potential of the atmosphere within the load. By the time the atmosphere has swirled around the work basket and reached the top of the reaction chamber, there to entrain fresh carburizing agent, the secondary cracking of the previously introduced carburizing agent has been substantially completed, at least to such extent the hot gases do not materially affect the rate of carburization when again passed through the load to serve as a vehicle for the fresh carburizing agent.

The hot gases, aside from serving as a vehicle for entraining and transporting the carburizing agent and its dissociation products, because of their movement in the work basket, maintain

uniformity of temperature of the work pieces throughout the load. Swirling and/or high velocity circulation of the vehicle gas, though desirable, are not essential to all aspects of my invention.

To prevent building up of pressure in the retort, the reaction chamber is vented to atmosphere, as by pipe 15, to allow escape of gases which, for purpose of safety to the operator, are ignited as by a gas flame, or electric spark, and burned. The positions of inlet 11 and outlet 15 are selected to minimize loss of freshly introduced agent. The gases so allowed to escape comprise principally carbon monoxide, methane and hydrogen. The ratio of the quantities of these gases to each other (for example, at desired rates of feed of agent, and with a furnace and load above described) varies considerably depending upon the speed of rotation of the fan 9, as shown by the following table:

	1800 R. P. M.	1200 R. P. M.	600 R. P. M.
	Percent	*Percent*	*Percent*
CO	20.4	22.1	21.8
CH_4	7.1	21.8	24.6
H_2	68.7	52.4	48.9

In brief, fan speed or speed of circulation materially affects the composition of the gases exhausted at 15, but is of less import in its effect upon carburization of the load, as will appear from the following: when the carburizing agent is introduced into the vehicle gas just before its entrance into the load the fan speed is not critical or even, within broad limits, material insofar as the ultimate carburizing results are concerned; and specifically within the range of 600 revolutions per minute to 2400 revolutions per minute, for example, does not materially affect the total depth or composition of the case. And yet, with the fan idle—no forced circulation of the vehicle gas—there is great lack of uniformity in total depth and composition of the case for different parts of the load and marked decrease in total depth of case for all parts of the load. For the particular furnace and under the conditions above specified, a fan speed about 1750 or 1800 revolutions per minute was preferable.

The fan 9, shown in Fig. 1, is of the blower type. The vanes 16 cause the gases discharged from the fan to swirl about the work basket as they advance upwardly in the reaction chamber thus to afford time for substantial completion of secondary cracking, by increasing the time required for the gases to pass from the fan to the top of the load; and the swirling action contributes to even distribution of the carburizing agent and its entraining gases in the space between cover 2 and the top of the load and before the agent or its primary dissociation products contact the work pieces.

I have discovered the erratic, non-reproducible results often obtained with various carburizing agents is due to presence therein of water in concentrations small enough previously to have escaped detection, but nevertheless having marked and variable effect upon the carburizing power of the atmosphere, because causing therein existence of decarburizing agents such as water vapor and carbon dioxide. Accordingly when the carburizing agent is a liquid, vapor, or gas, particularly one of those now known or found to contain water, a dehydrator of any suitable type, generically indicated at D, should be included in the supply line 11 in advance of its connection to the furnace. Dehydrator D may be of any known type; for example, the water may be removed from a carburizing liquid, vapor or gas by centrifugal action in accordance with the well-known principles of centrifugal separators; when there is substantial difference between the boiling points of a particular carburizing liquid and of water, the separation may be effected by distillation; or a suitable hygroscopic substance, in liquid, solid, or gaseous form may be utilized to absorb the undesirable moisture from the carburizing gas or vapor before its introduction into the carburizing furnace.

Although in reference to Fig. 1, the gases, after having once passed through the load have been specifically described as recirculated therethrough, it is to be understood that they may be discharged to waste after having once passed through the load as specifically described in subsequent modifications. In either event, it is provided that the atmosphere in contact with the work shall comprise substantially exclusively the products of primary dissociation or cracking of the agent, shall not be subject to secondary cracking, and that there shall be inappreciable cracking of freshly introduced agent prior to its contact with the load.

In the modification shown in Fig. 2, the fresh carburizing agent is introduced, in liquid, gaseous or vapor phase, into the top of the furnace in aforesaid essential proximity to the work where it is entrained by hot gases flowing from the duct 17. The treating atmosphere, consisting of the carburizing agent and the hot carrier gases, is immediately drawn downwardly through the load in the work basket 4 by the fan 9, of any type suitable to the purpose. As in Fig. 1, the provision for adding fresh carburizing agent into hot vehicle gases just before they reach the load, permits attainment of high and uniform carburizing power or potential of the treating atmosphere throughout the load; the carburization is effected by the products of the primary cracking reactions to the substantial exclusion of carburizing effects by the products of secondary cracking reactions, involving, for example, rupture of hydrogen to carbon bonds.

The atmosphere after once passing through the load may be discharged to waste through the duct 18 on the discharge side of fan 9 at the bottom of the retort, or, preferably, the treating atmosphere after once passing through the load is directed, as by duct 18a, to a chamber 19 of a secondary cracking furnace CF, which may contain brick checkerwork CW, and which is heated, as for example by electrical resistors 20, to temperature substantially in excess of 1700° F. to complete at high rate the cracking of carburizing agent or any crackable carbonaceous material discharged from the load. The cracking may be facilitated by the presence of a suitable catalyst, such as nickel. The gaseous product of this cracking comprising molecular hydrogen or molecular hydrogen and carbon monoxide, depending upon the composition of the carburizing agent, is directed to the carburizing chamber C by conduit 21 connected to the pipe 17 in the cover of the furnace, thus to serve as the body or stream of hot gas which again entrains carburizing agent and functions as a vehicle for carrying it and its dissociation products rapidly downwardly through the load. Soot resulting from cracking in the cracking furnace CF is

trapped in the checkerwork CW which should be cleaned at suitable intervals.

The stable vehicle gas so returned to the furnace is substantially free of soot, and of components otherwise substantially capable of lowering the carburizing power of the atmosphere in the carburizing chamber, or of lowering the carbon concentration at the surface of, or capable of interfering with maintenance of carbon saturation of the surface of the work.

Preferably the currents of the gases to and from the cracking chamber 19 are brought into heat transfer relation with each other, as by a suitable heat exchanger 22, to raise the temperature of the gases discharged from the carburizing furnace C before they enter the cracking furnace CF, so to reduce the amount of heat essential for the cracking in furnace CF, and concurrently to reduce the temperature of the gases moving toward the carburizing furnace more or less closely to approximate the desired temperature of carburization.

In the system shown in Fig. 3, the treating atmosphere after once passing through the load in furnace F similar to that of Fig. 2, is subjected, externally to that furnace, to treatment effecting a transformation of its carbonaceous components by converting them into hot, substantially non-carburizing gases. Specifically, the treating atmosphere after passing once through the load in furnace F is discharged through the duct 18*a* extending to the combustion chamber 19*a* to which air is supplied, as by pipe 23, in quantity to effect combustion (sufficiently incomplete substantially to prevent production of CO_2 which in furnace F would cause decarburization) of the carbonaceous components of the gases from furnace F; the products of the incomplete combustion are principally carbon monoxide, molecular hydrogen and water vapor, which pass from the combustion chamber 19*a* to furnace F through conduits 21 and the condenser 24 wherein they are cooled, as by flow of water or other suitable fluid through the coil 25, sufficiently to condense the water vapor to dehydrate the gases before their return to furnace F; the condensate discharges to waste through the pipe 26 and the liquid seal 27. The remaining gases, principally nitrogen and carbon monoxide, flow through inlet pipe 17 into the top of the carburizing furnace F.

Preferably, the gases to and from the condenser 24 are brought into heat transfer relation with each other by means of a suitable heat exchanger 22, in order that the gases leaving the condenser may be raised in temperature by gases flowing from the combustion chamber 19 toward the condenser, thus to reduce the amount of heat necessary to supply the furnace F to maintain carburizing temperature.

The vent pipes 15*a* of Figs. 2 and 3 serve the same purpose as pipe 15 of Fig. 1.

Without sacrifice of uniformity of the carburized case throughout the load, the time required to produce a desired case on the work pieces may be substantially decreased by beginning the run with such high rate of feed of carburizing agent that the surface of the steel throughout the load is saturated with carbon in the shortest possible time limited only by the ability of the particular steel to absorb carbon at the carburizing temperature and thereafter decreasing the rate of feed of the carburizing agent in conformity with the decreasing ability of the steel to absorb carbon, while still maintaining its surface saturated with carbon.

Referring to Fig. 4 as illustrative of a typical run conducted in accordance with my invention, the carburizing agent, specifically fusel oil, was fed, at the beginning of the run, at the rate of 1600 cubic centimeters per hour (cc./hr.), curve F, which rate if continued throughout the run, would have been so high as to cause heavy deposits of soot and non-uniformity of the case. At the end of an hour, the rate of feed was decreased to 600 cubic centimeters per hour (cc./hr.), curve F, and maintained at that rate for the remainder of the run, which rate for the particular furnace, type and amount of load, and particular carburizing agent employed, is not so high as to result in harmful amount of soot. The curves T and H illustrate respectively the progress of formation of the total case and of the hypereutectoid component of the case, when the rate of feed was changed as described. The desired depth of case may be obtained by terminating the run at the time indicated necessary by curves T and H.

The ratio of the total depth of case to the depth of its hypereutectoid component may be varied by manually or automatically varying or changing the rate of feed of the carburizing agent in accord with the program essential to that result. When the initial rate of feed of the carburizing agent, fusel oil, was maintained at 1200 cc./hr., curve F', Fig. 5, for the first hour of the run, and then dropped to 400 cc./hr., the rates of formation of the total case and its hypereutectoid component were those shown by curves T' and H', respectively, of Fig. 5.

By comparison of Figs. 4 and 5, it is seen that by stopping at the end of three hours, the total depth of case obtained with both programs is very closely the same, .040'', but the hypereutectoid comprises 30% of the total depth of case in Fig. 4, whereas the hypereutectoid is, in Fig. 5, 35% of the total depth of case.

Thus the hardener by selection of the proper program may reproduce cases having both the desired total depth and the desired percentage of hypereutectoid.

Selection of the ratio of depth of hypereutectoid to total depth for a desired total depth of case is also possible by selection of the carburizing agent. For example, the operating conditions, including rate of feed of agent, under which curves T^2 and H^2 of Fig. 6 are obtained are the same as those obtaining for Fig. 5 except that diethyleneglycolmono-ethylether is used instead of fusel oil. By terminating the run at five and one-half hours, for example, to obtain a total case depth of .040'', (the same obtained in Figs. 4 and 5 by a three-hour run) the depth of hypereutectoid if approximately 20% of the total depth of case, whereas for aforesaid same total case depth in Figs. 4 and 5, depths of the hypereutectoid components are 30% and 35%, respectively, of the total case depth.

In the run exemplified by Fig. 6, the decrease in rate of supply of agent at the end of an hour was so great the depth of hypereutectoid component of the case decreased for nearly an hour thereafter, notwithstanding continuous supply of fresh carburizing agent; during the latter period, the carbon diffused into the steel from its surface hypereutectoid case at a rate greater than the surface of the steel absorbed carbon from the furnace atmosphere. To prevent this and obtain higher percentage of total depth of the hypereu-

tectoid component, the rate of feed of agent is maintained high for a longer time at the beginning of the run or not so abruptly decreased.

If maximum rate of carburization throughout the run is desired, the rate of feed of the carburizing agent may be so decreased that throughout the run the carbon available in the carburizing atmosphere for transfer to the steel is at all times approximately equal to the amount of carbon which the steel at that time is capable of absorbing, while maintaining the surface of the work saturated with carbon. In other words, to accommodate the carbon-absorbing ability of the steel which, notwithstanding its surface continues saturated with carbon, decreases during progress of the run, the rate of feed of agent is progressively decreased sufficiently to avoid excessive deposition of free carbon or soot, yet progressively maintaining the rate of supply of carbon transferable to the steel from the treating atmosphere sufficient to satisfy the progressive capacity of the steel to absorb carbon. Otherwise stated, throughout the run, and particularly at the beginning thereof, there is maintained throughout the load the highest carburizing power of the atmosphere which is not productive of soot in harmful amounts. By introducing the carburizing agent where herein described, it for the first time has become possible in practice fully to satisfy the carbon-absorbing capacity of the steel, always highest at the beginning of a run, without formation of free carbon or deposition of soot on the work in quantities preventing or materially interfering with carburization.

When a program such as above referred to—which involves a variation of the rate of feed of carburizing agent to accord with the characteristic absorption-rate of carbon by the particular steel—is followed, control of the percentage of total depth of case represented by the hypereutectoid component is obtained by selection of the carburizing agent.

It is also possible to control the percentage of total depth of the hypereutectoid component by saturating the surface of the steel with carbon early in the run, preferably in the shortest time possible, and thereafter cutting off the supply of carburizing agent for a suitable time or for the remainder of the run while continuing circulation of the vehicle gas and maintaining the temperature of the work. When the supply of agent is cut off, or less desirably substantially reduced, the circulating gas no longer supplies carbon to the steel, thus ending an active carburizing period, the carbon in the saturated surface and sub-surface diffuses inwardly to increase the total depth of case with concurrent reduction of the depth of the hypereutectoid component. During the period of active carburizing, the entire surface of the load is subjected to products of the primary cracking of the agent which saturate it with carbon and maintain its saturation as carbon diffuses therefrom into the sub-surface; during the aforesaid inactive or diffusion part or parts of the run, especially when the supply of agent is reduced substantially to zero, all parts of the load are exposed to an atmosphere, specifically the stable or neutral carrier gases, having uniform temperature and composition, thus insuring maintenance of uniformity of case characteristics throughout the load during the diffusion of carbon inwardly from the load surface.

For any part of the aforesaid programs, the rate of feed of carburizing agent may be varied by an operator in accordance with a time-feed chart showing the proper rate of feed throughout the run, or the rate of fed may be varied automatically, as by control apparatus generally of the type shown in Stammberger Patent No. 2,025,134, in accordance with a predetermined schedule or program.

The time-feed charts are prepared from data obtained during test runs during which, at suitable intervals, test specimens are removed from the load and their surface and sub-surface characteristics noted. The data thus obtained is used to plot curves, such as T, H of Figs. 4 to 6; on the same sheet may be plotted the flow or feed curve.

In the system of Fig. 7, my invention is applied to a continuous type furnace as distinguished from the batch type furnaces of Figs. 1 to 3. The perforate conveyor 28 which moves at suitably slow rate, either continuously or intermittently, receives work pieces dumped from time to time into the chute 29 which is provided with a door 33 which yields to allow passage of the pieces. The fans 9, spaced below and along the conveyer, draw through the load, comprised of the work pieces spread along the conveyer, the furnace atmosphere which consists of carburizing agent supplied by pipes 11 and hot vehicle gases fed by pipes 17. The exhaust from the fans leaves the carburizing chamber, as by ducts 18, and preferably is returned to the top of the reaction chamber through pipes 17 after passing through an arrangement such as shown in Fig. 2 or Fig. 3 for conversion into stable vehicle gases having insubstantial effect upon the steel. These hot gases, as in the modifications of Figs. 2 and 3, entrain freshly introduced carburizing agent, assist in vaporizing the agent when introduced into the furnace in liquid phase, and serve as a medium for maintaining uniformity of the temperature of the work pieces. Since the fans divide the chamber C into more or less distinctly defined zones, programming may be effected by feeding the carburizing agent at different rates to different zones; for example in the zone or zones, nearest the intake chute 29, the carburizing agent may be fed at high rate thus to subject each piece of work at the beginning of its run to an atmosphere capable of transferring carbon at high rate commensurate with the ability of the steel then to absorb carbon. In subsequent zones, the carburizing agent may be fed at progressively lower and lower rates or the rates of feed at the subsequent zones may be equal to each other but lower than at the first zone. Different carburizing agents may be fed to different zones affording still wider latitude in the selection of the desired depth of total case and of the desired depth of hypereutectoid case. The time of treatment is controlled by selection of the speed at which the conveyer 28 operates, assuming it runs continuously; if the conveyer operates intermittently, the total time a particular piece is subjected to the carburizing atmosphere may be varied by changing the length of the interval between successive operations of the conveyer.

As each work piece arrives at the discharge end of the furnace it drops from the conveyer into a suitable quenching bath in tank 31. The level of the bath is above the end of the discharge chute 32 to prevent escape of the furnace gases.

The furnace may be heated in any suitable known manner, as by resistors 13 suspended from the side walls of the furnace and suitably shielded from direct contact with the carburizing at-

mosphere, or by combustion of liquid or gaseous fuel and air in a chamber suitably isolated to prevent the products of combustion from entering the carburizing chamber.

The furnace construction shown in Fig. 8 is substantially the same as that of preceding forms except for the method of heating the retort. Instead of using electrical resistors, the retort is heated to desired temperature by combustion in the annular heating chamber 14 of the furnace. Specifically, one or more burners 35 supply to the chamber 14 a suitable combustible mixture, for example a mixture of fuel gas or oil and air to the bottom of the chamber 14 where it is ignited, as by an electric jump spark device 36, which may be similar to the jump spark devices 36a for igniting the furnace gases which escape from vent pipe 15, Figs. 8, 9 and 10. Preferably the burners are directed tangentially of the heating chamber to cause the injected mixture and the products of combustion to swirl about the retort 1 as they advance axially thereof toward the outlet duct 37 at or near the upper end of the heating chamber. As indicated, the combustion chamber 14 is isolated from the reaction chamber C to prevent any of the gases in the combustion chamber from entering the reaction chamber, and vice versa. The specific seal construction shown in Fig. 8 for that purpose is not herein described, but is specifically described and claimed in my copending application Serial No. 184,554, filed January 12, 1938.

In the preceding description of Fig. 1, it was stated that when the carburizing agent was introduced into the furnace in liquid form there was preferably provided the vaporizing plate 12 to prevent unvaporized liquid, dropping from the inlet pipe 11, from impinging upon the work and causing a cold spot.

In the alternative arrangement shown in Fig. 9, the vaporizing plate 12 may be dispensed with and the possibility of unvaporized carburizing liquid reaching the work minimized by injecting the liquid at high pressure in the form of a fine spray. Any suitable injection nozzle 38, for example, of the type used for fuel injection in Diesel engines, may be employed; the nozzle should be adjusted to give a fine spray distributed through a large angle. When the carburizing liquid is introduced or injected into the furnace in this finely divided form, there is practically no possibility that any of it will reach the top of the work in unvaporized state. The hot gases swirling upwardly between the retort 1 and the outside of the work basket 4 meet the spray in the top of the furnace, immediately vaporize it, and raise the vapor to dissociation temperature slightly before or as it reaches the top of the work. This mode of introducing the carburizing agent may, of course, be utilized in any of the furnace constructions herein illustrated and described.

In the furnace construction shown in Fig. 10, the fan 9a is of the propeller type and has low blade angle to avoid any substantial blower or centrifugal action. For one direction of rotation of the fan, the gases, as in the modifications herein previously described, swirl upwardly within the retort 1a outside of basket 4, and thence downwardly through the load, whereas for reverse direction of rotation of the fan the gases pass upwardly through the load and then swirl downwardly externally of the work basket to the intake side of the fan. When the fan is rotating in such direction the gases pass downwardly through the load, the fresh carburizing agent, in accordance with the methods herein described, is injected or introduced into the upper end of the reaction chamber C, as by nozzle 38, whereas when the fan is rotating in reverse direction to pass the gases upwardly through the load, the fresh carburizing agent is injected or introduced, as by the Diesel nozzle 39, or equivalent, into the region between the fan 9a and the grid 8 in the bottom of the work basket.

Thus for either direction of rotation of the fan it is ensured the fresh carburizing agent shall be introduced into the circulating vehicle gases just before or as they enter the load. Therefore, with this arrangement, for either direction of circulation, the zone of primary cracking of the carburizing agent is again confined to and comprehends the load zone, whereas were only one nozzle or equivalent provided, for one of the directions of rotation of the fan, the primary cracking of the agent would begin too remote from entrance of the products of the cracking into the load, with consequent deposition of soot.

The selection of either of the points or regions of introduction of the carburizing agent and/or the reversal of the fan to accord with the selected point or region may be effected manually, but preferably both operations may be concurrently performed by a suitable automatic system.

Referring to Fig. 11, which discloses a control system suited for that purpose, the control valves 40, 41, for connecting the agent feed pump 42 to one or the other of the injection nozzles 38, 39, are controlled respectively by solenoids 43, 44, having a common terminal 45 connected to one conductor 46 of a three-phase source of current 47. When switch 48 is closed, relay 49 is energized from any suitable source, as for example one phase of the source 47, to effect movements of its contacts 50, 51, 52 to closed circuit position. Closure of contact 50 effects energization of the solenoid or magnet 43 to open valve 40 allowing the feed pump 42 to deliver carburizing agent to the upper nozzle 38 of the furnace through the feed line 53. Closure of contacts 51, 52 effects energization of the fan motor 10 from the three-phase source 47 for rotation in such direction the carburizing atmosphere flows downwardly through the load in the work basket 4 and thence upwardly through the space between the work basket and the retort 1a. When switch 54 is closed for reversal of the direction of circulation of the treating atmosphere in the furnace, the relay 55 is energized to effect circuit-closing movements of its contacts 56, 57 and 58, and the mechanical coupling between the switches 54 and 48 insures that concurrently with the energization of relay 55 the relay 49 is deenergized to effect closure of valve 40 in the supply line between pump 42 and the upper nozzle 38. Closure of contact 56 of relay 55 provides for energization of the magnetic operator 44 of the valve 41, causing pump 42 to supply carburizing liquid through the lower feed line 59 to the lower injection nozzle 39. The closure of contacts 57 and 58 again connects motor 10 to the three-phase source 47 but with reverse connections to one phase to effect rotation of the fan motor in opposite direction, i. e., in such direction the gases within the reaction chamber C are forced upwardly through the load and thence downwardly in the space between the retort 1a and the work basket 4. The reversal of the direction of circulation and the concurrent reversal of region of introduction of fresh carburizing agent may be effected at suitably short intervals, for example, every 2 minutes, or the intervals be-

tween successive reversals may vary throughout the run; for example at the beginning of the run the reversals may be more frequent than later in the run.

Though particularly suited for carburizing, the system and furnace of Figs. 10 and 11 may be used for other modes or types of heat treatment, involving use of reactive or protecting atmospheres, such as nitriding, bright annealing, tempering, hardening, and the like.

Reference in appended claims to the place of introduction of the carbonaceous material into the vehicle gas as adjacent its first contact with the load shall be construed as comprehending only such distance between the place of introduction and the first contact with the load and such velocity of transport of the material between the place of its introduction and first contact with the load that carburizing products of dissociation or cracking of that material are not formed or do not exist in substantial quantity in the gas stream prior to its first contact with the load; and I disclaim from aforesaid construction introduction of the carbonaceous material into the vehicle gas external to the furnace, as well as subjection of the mixture in advance of its first contact with the load to such condition or structure within the furnace as to effect production in substantial quantity of carburizing products of cracking or dissociation of the carbonaceous material.

What I claim is:

1. The method of carburizing which comprises passing a vehicle gas in contact with the load, introducing carbonaceous material into the vehicle gas in advance of and adjacent its first contact with the load, and subjecting the load to the resulting carburizing reagent.

2. The method of carburizing which comprises passing a vehicle gas in contact with the load, and subjecting the surface of the load throughout to carburizing reagent having maximum carburizing potential by introducing carbonaceous material into the vehicle gas in advance of and adjacent its first contact with the load.

3. The method of carburizing which comprises passing a vehicle gas in contact with the load, and saturating the load surface throughout with carbon by introducing a carbonaceous material, characterized by molecules comprising at least two mutually bonded carbon atoms, into the vehicle gas in advance of and adjacent its first contact with the load.

4. The method of carburizing which comprises passing a vehicle gas in contact with the load, procuring a carburizing reagent, effective throughout the load, by introducing a carbonaceous material into the vehicle gas in advance of and adjacent its first contact with the load, and so controlling the rate of introduction of said carbonaceous material into the vehicle gas that the surface of the load throughout is maintained saturated with carbon with simultaneous substantial prevention of production of soot in quantity substantially interfering with the passage of the vehicle gas in contact with the load.

5. The method of carburizing which comprises passing a vehicle gas in contact with the load, procuring a carburizing reagent, effective throughout the load, by introducing a carbonaceous material into the vehicle gas in advance of and adjacent its first contact with the load, and reducing the tendency to deposition of soot upon the load by limiting the rate of introduction of carbonaceous material into the vehicle gas to such magnitude that production from said material of carburizing reagent takes place throughout the load and substantially solely within the limits of the load zone.

6. The method of carburizing which comprises passing a vehicle gas in contact with the load, procuring a carburizing reagent, effective throughout the load, by introducing a carbonaceous material into the vehicle gas in advance of and adjacent its first contact with the load, recirculating the vehicle gas in contact with the load, and between exit of the vehicle gas from and reentry into contact with the load converting into non-carburizing products carbonaceous material remaining in the vehicle gas after its passage in contact with the load.

7. The method of carburizing which comprises passing a vehicle gas in contact with the load, introducing a carburizing agent into the vehicle gas in advance of and adjacent its first contact with the load, beginning adjacent and thereafter throughout the load effecting primary dissociation of said agent, and so controlling the rate of introduction of carburizing agent into the vehicle gas that the load throughout its surface is saturated with carbon.

8. The method of carburizing which comprises passing a vehicle gas in contact with the load, introducing a carburizing agent into the vehicle gas in advance of and adjacent its first contact with the load, beginning adjacent and thereafter throughout the load effecting primary dissociation of said agent, recirculating the vehicle gas in contact with the load, and between exit of the vehicle gas from the load and its reentry thereinto subjecting it to such temperature as to dissociate into non-carburizing products carbonaceous material remaining in the vehicle gas after its passage in contact with the load.

9. The method of carburizing which comprises passing a vehicle gas in contact with the load, introducing a carburizing agent into the vehicle gas in advance of and adjacent its first contact with the load, beginning adjacent and thereafter throughout the load effecting primary dissociation of said agent, recirculating the vehicle gas through the load, and between exit of the vehicle gas from the load and its reentry thereinto by incomplete combustion converting the carbonaceous material therein into neutral gas.

10. The method of carburizing which comprises passing a vehicle gas in contact with the load, introducing a carburizing agent into the vehicle gas in advance of and adjacent its first contact with the load, beginning adjacent and thereafter throughout the load effecting primary dissociation of said agent, and so controlling the rate of introduction of carburizing agent into the vehicle gas that the surface of the load is maintained saturated with carbon with simultaneous substantial prevention of production of soot in quantity substantially interfering with contact of the vehicle gas with the load.

11. The method of carburizing which comprises repeatedly circulating a vehicle gas throughout the load in contact therewith, introducing a carburizing agent into the vehicle gas, and preventing deposit of soot upon the load upon reentry of the vehicle gas thereinto by separating the soot from the vehicle gas between its exit from and return into the load.

12. The method of carburizing which com-

prises repeatedly circulating a vehicle gas throughout the load in contact therewith, introducing a carburizing agent into the vehicle gas, and between exit from and reentry of the vehicle gas into the load converting the soot into gases.

13. The method of carburizing which comprises saturating the entire surface of the load with carbon in the minimum possible time at the beginning of the run, by subjecting it to an atmosphere having throughout the load maximum carburizing potential, and thereafter maintaining uniformity of the carburizing potential of said atmosphere to maintain the aforesaid saturation of the entire load surface.

14. The method of carburizing which comprises at the beginning of the carburizing treatment feeding carbonaceous material to a vehicle gas at high rate rapidly to form a hypereutectoid case on the work, and after a predetermined time substantially decreasing the rate of feed of the carbonaceous material.

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