RADIANTLY HEATED CONTROLLED ATMOSPHERE FURNACE

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This invention relates to industrial furnaces for metal heating for the purpose of mechanical working, heat treatment, carburization, and similar purposes, and particularly to furnaces utilizing radiant heating elements such as electric resistance elements, radiant tubes or externally heated rotors or muffles. More particularly the invention relates to the production and maintenance of gaseous atmospheres for industrial furnaces of the above-mentioned nature.

One of the objects of the invention is to combine the radiant heating effect of such elements with the convection and combustion heating of hot combustion gases while maintaining a non-scaling atmospheric condition in the furnace in contact with the work to be heated.

Another object is to produce such a gaseous atmosphere which is carburizing in nature, or having a carburizing potential balanced to the carbon content of the metal to be heated.

A further object is to provide a controlled atmosphere furnace in which the heat is supplied primarily by radiant heating elements and in which the atmosphere is supplied by the hot products of combustion of an exothermic gas generator.

Another object is to provide a novel lithium vapor containing gaseous atmosphere for a radially heated furnace.

Other objects and advantages of the invention will hereinafter appear.

In accordance with the present invention we provide a furnace having as its principal heating means radiant elements such as electrical resistors, radiant tubes, and the like, by which heat is generated in the work chamber of the furnace independently of the admission into the chamber of any gaseous reaction products, and we supplement the heat so produced and at the same time provide a protective atmosphere for the work by admitting into the chamber hot products of a completed exothermic reaction of fuel and air, into which has been introduced a sufficient quantity of either a raw gas or the vapor of lithium or both to overcome or neutralize the normal scaling tendencies of such gaseous products. The raw gas, when employed, is added directly to the furnace chamber whereas the lithium vapor may be introduced into the gaseous products before, during, or after introduction of the hot gases into the furnace chamber or partially before and partially during or after such introduction.

Ordinarily in furnaces heated by radiant heating elements the atmosphere of the furnace consists of air entering through the various openings into the furnace, or an inert gas, such as nitrogen or dry hydrogen or a prepared combustion gas, such as exothermic or endothermic reaction products which have been dehydrated by refrigeration. Whatever the atmosphere herefore employed, it ordinarily has consisted of a cold gas, which when introduced into the furnace chamber may be brought up to furnace temperature by the radiant heating elements and therefore, instead of augmenting the heating effect of such elements, subtracts heat therefrom. In the case of cooled exothermic and endothermic reaction products, this represents not only a loss in the work heating capacity of the radiant elements but a total loss of the available heat from the fuel employed to produce the reaction products and a further loss of energy expended in the refrigerating apparatus employed to dehydrate the gases.

It has not been feasible heretofore to introduce the hot combustion gases into the furnace chamber directly from the gas generating chamber since to do so would defeat the purpose for which the radiant or indirect heating is normally employed, namely, to prevent scaling of the work by contact with ordinary combustion gases. The present invention represents a departure from prior practice in permitting hot combustion gases to be utilized not only to impart heat to the work but to serve as a protection for the work against scaling.

This result is obtained by a combination of controlled combustion of the fuel employed to generate the furnace atmosphere gas, control of the raw gas additions when employed, and by the chemical treatment of the furnace gases by the vapor of lithium.

Lithium has been employed heretofore to create neutral furnace atmospheres by addition to dehydrated or partially dehydrated reaction products and also by introduction into the atmosphere of a combustion furnace as by spraying a powdered compound thereof into the furnace chamber. The present invention is to be distinguished from these prior processes in a number of important respects, as will appear as the description proceeds. Fundamental among these distinctions, however, is the provision of a gas generating chamber independent of the furnaces from which completely reacted gaseous products in their heated condition are supplied to the furnace chamber in sufficient quantity to maintain a positive pressure in the furnace but insufficient to have a controlling effect on the temperature of the furnace, this control being maintained at all times by the radiant heating means.

As a result, the combustion chamber may be operated at temperatures which will produce the most desirable CO₂/CÖ ratio for the prevention of scale formation. For instance, the furnace may be operated at 1800° F. under pyrometer control of the radiant heating elements. If heated to this temperature either solely or supplementary by burners, the resulting combustion gases, with the most suitable adjustments thereof for producing such temperature at a practical rate, would have a CO₂/CÖ ratio of not less than about 0.5 and an H₂O/H₂ ratio of about 0.8. At a temperature of 1800° F. both of these ratios are to the right or on the oxidizing side of the equilibrium ratio curves, the equilibrium or neutral values at this temperature for the reactions: Fe₂+CO₂, Fe₂+H₂O, Fe₂+CO, and Fe₂+O₂, in pure gases, being about 0.39 for CO₂/CO and 0.63 for H₂O/H₂.

When high temperature combustion is employed under conditions by which the combustion reactions are entirely completed in the gas generating chamber, through the proper geometry of the chamber and the location and size and control of the burners, we are able to obtain materially lower CO₂/CO ratios while maintaining the H₂O/H₂ ratio substantially constant. Thus, in a combustion chamber constructed in accordance with the present invention and operating at 2100° F. to 2200° F., a CO₂/CO ratio of about 0.35 or lower is obtainable with the H₂O/H₂ ratio remaining at about 0.8. The exact temperature at which such ratios will be obtained depends, of course, upon the fuel employed, the characteristics of
the burner, and the construction of the generating chamber. At this elevated temperature the gas is still oxidizing to steel but upon introduction of this gas into the furnace in such amounts as not to take the control of the furnace temperature from the radiant heating elements, this gas will impart some of its heat to the work and come into temperature equilibrium with the furnace. Moreover, with the combustion reactions entirely completed in the gas generating chamber, that is, with all of the hydrocarbons in the fuel reduced to CO, CO₂, H₂O, and H₂, and these brought into their normal equilibrium, the ratios thus established at the elevated temperature are retained at the lower furnace temperature. In the example given, the CO₂/CO ratio of the externally generated gas, when the gas is cooled to 1800°F., will be retained at about 0.35 and at this temperature such ratio is still on the oxidizing side but the total oxidizing potential of the gas has been greatly diminished and conditions approaching a neutral atmosphere are obtained in the furnace. At temperatures below 1800°F. this condition is even more pronounced.

In some instances we prefer, in addition to the foregoing procedure, to introduce a small amount of a raw hydrocarbon fuel, either gaseous or liquid, into the furnace chamber in such manner that it will be at least partially endothermically by the heat of the radiant elements. Such additions serve to enrich the furnace gases and thus further increase the CO and H₂ content of the atmosphere relative to the CO₂ and H₂O content. Such an atmosphere may be non-scaling at temperatures in the neighborhood of from 1600° to 1800°F. At still higher temperatures or at the lower temperatures in line of the raw hydrocarbon additions, the oxidizing effect of the water vapor may be overcome by the addition to the furnace gases of the lithium vapor referred to. Thus in the production of neutral heating atmospheres at about 2000°F. or lower, we prefer to employ the combination of a combustion gas produced externally of the furnace chamber to have a CO₂/CO ratio of about 0.35 and the addition of lithium vapor to reduce the H₂O/H₂ ratio. Above 2000°F. the relative advantage in the reduction of the CO₂/CO ratio by the external combustion chamber burners firing directly into the furnace, although of material assistance, is less pronounced and hence in addition thereto we prefer to utilize the reducing effect of both the raw gas additions and the lithium vapor additions.

However, we find that we can produce carburizing atmospheres at temperatures of from 1700°F. to 1800°F. by employing suitably regulated amounts of raw gas additions in combination with the lithium vapor additions and the externally produced gas having a low CO₂/CO ratio. Furthermore, we can control the potency of this carburizing gas, at any temperature, by the amount of the raw gas additions. At lower temperatures the CO content of the gas produced at a high temperature externally of the working chamber may be sufficiently high to produce carburization without or with only small raw gas additions.

As heretofore stated, the production of the optimum CO₂/CO ratio in the external chamber is dependent upon the construction thereof. In general, a number of small combustion chambers is more effective than a single large one. The combustion chamber preferably should be constructed so as to produce a maximum of scrubbing action in the burning gases with the walls thereof to thereby utilize the full catalytic effect of the hot refractories in promoting the combustion reactions. In practice, a cylindrical chamber of relatively small diameter and of appreciable length has been found extremely suitable, with the burners firing tangentially at one end to produce a spiral travel of the gases in contact with the walls and with the outlet at the opposite end, to give the maximum length of travel of the gases. The burners should be of the short flame type in order to effect combustion to a large extent in the burner blocks so that the gas generating chamber will have full opportunity to complete and stabilize the combustion reactions. The period during which the gases are retained in the gas generating chamber, the length of travel of the gas in contact with the hot refractory walls, and the degree of intermingling of the reaction products are of importance in the success of the process and should be so determined as to insure a complete reduction of all hydrocarbons into their constituents, reaction thereof with oxygen, and stabilization of the resulting gases. Preferably, the outlet of the chamber is of a restricted size so as to cause a substantial positive pressure to be developed in the chamber. Other considerations will appear in connection with the detailed description of the apparatus disclosed for carrying out the process of the invention, in which reference will be made to the accompanying drawings, in which:

Fig. 1 is a horizontal sectional view of an electric furnace and associated apparatus embodying the present invention;

Fig. 2 is a vertical sectional view of the gas generating chamber taken on the line 2—2 of Fig. 1;

Fig. 3 is a horizontal sectional view of the gas generating chamber taken on the line 3—3 of Fig. 2;

Fig. 4 is a vertical sectional view of the lithium vaporizing chamber taken on the line 4—4 of Fig. 1; and

Fig. 5 is a vertical sectional view of the vaporizing chamber taken on the line 5—5 of Fig. 4.

Referring first to Fig. 1, a furnace, which may be of any conventional form, is shown as comprising an outer shell 10 having a charging door 11 at one end thereof, a discharge door 12 at the opposite end thereof, and a refractory lining 13. The work is adapted to be entered through the door 11, conveyed through the furnace on a roller hearth 14 and discharged through the door 12.

The principal heating medium consists of electric resistance elements 15 carried on the side walls of the furnace by hangers 16 and having lead in terminals 17. If desired, similar heating units may be carried by the floor and/or the ceiling walls. The electric heating units are controlled in the usual manner by one or more thermocouples, not shown, so as to maintain the furnace at the desired temperature.

In the furnace shown, it is contemplated that the doors 11 and 12 will remain partially open during operation of the furnace to permit the work to be heated, such as bar stock, to be inserted into, through the furnace in a continuous manner. The door openings, therefore, serve as vents for the furnace atmosphere, which must be supplied in sufficient quantity to maintain a positive pressure within the heating chamber under the contemplated operating conditions.

As heretofore stated, we supply the furnace atmosphere with a combusted fuel gas generated externally of the furnace and introduced therein while in a highly heated state. For this purpose the furnace is provided with two small combustion gas generators 18, identical in structure and disposed at spaced points closely adjacent to the furnace.

As shown more clearly in Figs. 2 and 3, each of the combustion gas generators comprises a cylindrical shell 19, disposed vertically and having a refractory lining 21 defining an inner cylindrical chamber 22. Adjacent the top of the chamber 22 are burners 23 firing into burner blocks 24 aligned with their axis tangentially in the side wall of the chamber 22 so that the products of combustion enter the chamber at a relative high velocity and in a direction to spiral about the chamber 22 in scrubbing contact with the hot refractory walls.

The burners 23 are of the short flame type and the blocks 24 are sufficiently deep to permit the combustion reactions to be largely completed in the block. As a con-
sequence, the chamber 22 serves to break down the last remnants of the hydrocarbon fuel and causes a complete stabilization of the resulting products. Since this complete stabilization requires an appreciable time and a rather violent scrubbing action of the gaseous products, the chamber 22 preferably has a cubic capacity sufficient to retain the gases therein for the required time interval and to assure a high ratio of wall area to cubic capacity. These conditions are met by a combustion chamber having a small cross-sectional area relative to its length. In practice, we have found that a gas generator of circular section of one foot diameter and a length of one foot for each one thousand cubic feet of gas produced therein is well suited to the purpose. Such a generator will have approximately three square feet of wall surface per thousand cubic feet of generated gas and a surface area to volume ratio of 4 to 1. It is to be understood, however, that the above ratios are not critical and are given only by way of example.

The gaseous products are conducted from the chamber 22 by a conduit 25, of a sufficiently restricted section to cause a relatively high positive pressure, preferably of about 0.1 inch of water, to be maintained in the combustion chamber. This pressure assists in the stabilization of the gases and increases the period of retention of the gases in the chamber.

The refractory walls 21 of the chamber 22 should be of sufficient thickness and insulating nature to prevent material loss of heat by conduction therethrough and to maintain a high inner surface temperature to increase the catalytic effect thereof on the gases. A porous brick of high insulating properties is known which serves to render the highest inner-to-outer surface temperature ratio.

The gas generator 18 is secured to the furnace 10 by a coupling comprising a flanged tubular member 26 welded or securely secured to the furnace shell, and a tubular flanged extension 27 carried by the shell of the generator. The flanges 28 and 29 of these members are secured together in any suitable manner, as by bolts 31.

A lighting hole 32, closed by a refractory plug 33, is provided in the side wall of the gas generator 18, and the shell 19 has a threaded boss 34 surrounding the plug 33 and normally closed by a cap 35. A smaller opening 32', closed by a plug and cap, is provided in the top end wall of the chamber to provide access to the chamber for venting while bringing the furnace up to temperature.

In addition to the attainment of a completion and stabilization of the gaseous reactions, it is necessary to employ an air-to-fuel ratio in the burners 23 which is inherently capable of producing the desired composition of the resulting gaseous products. This will vary, of course, with the fuel employed, but by way of illustration, with natural gas a ratio of air to gas of from about 6 to 7 to 1 will be satisfactory. With city gas of 525 B. t. u. content, a ratio of 2.5 to 3 to 1 will be approximately correct. We prefer to supply this mixture to a number of small burners rather than to a single large one, and in practice we have found that good results are obtainable with burners which consume about 700 to 900 cubic feet of air and gas mixture per hour.

Referring to Fig. 1, the air and gas if supplied to the burners 23 from air and gas lines 36 and 37, respectively, through a zero regulator 38 in the gas line and a venturi mixing tube 39 by which the gas is induced by the flow of air therethrough, as is well known in the art. The air-gas ratio is controlled by the relationship between the air jet area in the mixer and the burner port area, and as stated should be such that when the proper combustion conditions are provided, as described above, the CO₂/CO ratio of the reaction products leaving the combustion chamber will be about 0.35. If a lower CO₂/CO ratio is desired in the furnace 10, this may be accomplished by introducing a small quantity of raw hydrocarbon fuel, such as propane, butane, methane, fuel oil, benzol, and the like, into the furnace. For this purpose, an induction tube 42 is provided for introducing such fuel into the outlet passage 25 of the gas generator, the tube 42 being supplied with fuel from a suitable source through the control valve 43.

The hydrocarbon fuel admitted by the tube 42 will be cracked down endothermically by the hot walls of the tube 25 and the highly heated gases passing therethrough to liberate carbon which reacts with the CO₂ of the generator gases to thereby decrease the CO₂ content of the gas and to increase its CO content. Obviously, the amount of hydrocarbon which can be cracked in the tube 25 is limited by the available heat in the gases from the generator 19. However, any excess gas admitted by the tube 42 will be carried into the furnace, in intimate intermixture with the hot combustion gases, and will be cracked down to its constituents by the radiant heating elements in the furnace and thus complete the reduction of carbon monoxide to the desired value. Thus, any desired ratio of carbon dioxide to carbon monoxide may be obtained in the furnace, down to an extremely low ratio which is highly carburizing in nature. In addition to this intermingling and reacting of the raw fuel with the combusted gas is assisted by a spiral insert 44 provided in the passage 25, which creates a high degree of turbulence of the gases.

In addition to the more thorough intermixing of the raw fuel and combusted gas obtained by adding the former in the passage 25, over introduction of the raw gas directly into the furnace chamber, we obtain the advantages of higher temperature cracking, since the combusted gases are at substantially their highest temperature in the passage 25. The advantages of high temperature cracking are more complete and active cracking and greater freedom from soot. For this reason it may be desirable to operate the gas generator 19 at even higher temperatures than those heretofore specified, for instance, up to 2300° F. to 2400° F.

In addition to reducing the CO₂/CO ratio, the raw fuel on cracking liberates hydrogen which serves to lower the H₂O/H₂ ratio and thus to render the entire furnace atmosphere less oxidizing in nature.

It has been found desirable, in order to eliminate sooting in the induction tube 42, to prevent cracking of the raw gas prior to its entry into the passage 25. Therefore, the tube 42 is provided with a cooling jacket 45 to which cooling air is supplied from the line 36.

If desired, as for instance, in creating a highly carburizing atmosphere in the furnace, additional induction tubes 42 may be extended directly into the furnace through the walls 13, the tubes 42 being supplied with gas and cooling air in the same manner as the tubes 42.

It is to be understood that the use of raw gas additions is not required under all conditions, the considerations which dictate its use being either the temperature of operation of the furnace 10 or the desirability of a carburizing atmosphere therein. As previously stated, the CO₂/CO ratio of about 0.25 attainable through the use of the external gas generator is, at temperatures of about 2000° or higher, oxidizing in nature, and hence at such temperatures it is advantageous to utilize the reduction in this CO₂/CO ratio obtainable by the raw gas additions. At lower temperatures the CO₂/CO ratio obtainable from the gas generator 18 is below the scaling ratio but not necessarily below the decarburizing ratio, particularly for high carbon steels. Therefore, if it is desired to maintain the carbon content of the steel being heated or to add carbon thereto, it is again desirable to reduce the CO₂/CO ratio by the raw gas additions to this reduction in the above ratio, the raw gas in cracking adjacent the work provides the nascent carbon required for effective carburizing. By controlling the amount of raw gas added to the furnace, it is thus possible to place the atmosphere in carbon balance with the steel or to add carbon to it to any desired carbon level.
There is one other factor, however, to be taken into consideration in obtaining the advantages inherent in the control of the CO₂/CO ratio of the furnace, namely, the scaling and decarburizing effects of water vapor on the work. Since the gas generator 18 supplies its gas directly to the furnace 10 in a highly heated condition, that is, without the usual precooling to eliminate water vapor therefrom, the water vapor content is relatively high, the ratio of H₂O to H₂ being about 0.8. This ratio being both scaling and decarburizing will nullify the carburizing potential of the CO₂/CO ratio obtained and may, in addition, cause scaling to occur even at the low CO₂/CO ratio conditions in the furnace.

In order to completely nullify the oxidizing and decarburizing effects of water vapor in the furnace and to enable the isodynamic effects on the steel to be controlled by the CO₂/CO ratio established in the furnace, we add to the furnace gases a minute quantity of the vapor of lithium compounds. This characteristic of lithium compounds has been disclosed in various patents and applications for patent of H. J. Ness, owned by the assignee of the present invention, and we make no claim to this phenomena except in combination with the CO₂/CO ratio control of the furnace atmosphere.

The lithium vapor generator 18 for supplying the lithium vapor to the furnace is shown in detail in Figs. 4 and 5, and comprises a horizontal cylindrical shell 47 having a refractory brick 48 to form a combustion chamber 49, and a burner 51 firing tangentially thereinto. Extending axially through the chamber 49 is an alloy tube 52 having an opening 53 therein by which the products of combustion from the chamber 49 may pass into the interior of the tube. One end of the tube 52 extends outwardly from the shell 47 and is adapted to be closed by a cap 54. The opposite end of the tube 52 extends through the furnace wall as indicated in Fig. 1.

Lithium compounds are inserted into the vaporizing tube 52 in the form of a fused cake 55 disposed within an alloy boat 56 secured to the end of a draw rod 57 and engageable with a lug 58 in the tube 52 so as to accurately position the boat within the tube centrally of the combustion chamber. The charge placed in the boat 56 preferably comprises a mixture of lithium carbonate and lithium chloride in the proportion of 50% of the former and 40% of the latter. Other compounds of lithium and other proportions may be employed.

The temperature of the vapor generator is preferably maintained at from 1400° F. to 1750° F. under control of a thermocouple 59, as is well understood in the art. This temperature range will create sufficient vapor pressure and gas for the burner 51 to effect the desired nullifying effect of water vapor as it is carried into the furnace by the passage of hot gases from the chamber 49 through opening 53 and over the boat 56 to the outlet passage 54.

Passage 54 is disposed closely adjacent to the outlet 25 of each of the gas generators 19 in order that the gases from the two passageways will intermingle and permit the lithium vapor to act upon the gases from the generator 19 at the time they enter the furnace chamber, although this adjacent relationship goes only to the effectiveness of the latter treatment rather than operativeness of it, and other relative arrangements may be employed.

While the lithium vaporizer is maintained at a somewhat lower temperature than the gas generator 19, the burner 51 is provided with a long burner block 60 in which high temperature combustion is obtained and to a large degree completed. Consequently, the CO₂/CO ratio of these gases, while slightly higher than those from the generator 19, will not materially raise the ratio of the gases in the furnace chamber since the volume of gas supplied by the lithium vaporizer is small in comparison with that supplied by the gas generators.

Air and gas to the block 51 are supplied from the air and gas lines 36 and 37 through an electric valve 61 and a manual valve 62 in branched conduits in the air supply line, and a venturi mixing tube 63, with the electric valve 61 under the control of the thermocouple 59, as is well known in the art.

It will be understood, of course, that variations may be made in the arrangement and construction of the various elements depicted without departing from the essential attributes of the invention, and we desire to include all such changes and modifications as come within the scope of the appended claims.

What is claimed is:

1. In an industrial furnace, the combination of a work heating chamber, radiant heating means for said chamber, control means for said radiant heating means for maintaining a predetermined temperature in said work chamber, means for supplying to said work chamber products of combustion which are substantially neutral to metal to be heated in said work chamber, said last mentioned means comprising a combustion chamber, burner means for supplying a combustible mixture of fuel and air having a high deficiency of air to said combustion chamber, the walls of said combustion chamber being composed of a refractory material having high heat insulating properties, whereby the inner surface of said chamber will be maintained substantially at the combustion temperature of said mixture, said combustion chamber having an outlet port of restricted cross-sectional area, whereby a substantially uniform pressure of the products of combustion will be maintained in the combustion chamber and a conduit extending directly from said outlet port to said work heating chamber, said conduit being composed of a refractory material having high heat insulating properties.

2. In an industrial furnace, the combination of a work heating chamber, radiant heating means for said chamber, control means for said radiant heating means for maintaining a predetermined temperature in said work chamber, means for supplying to said work chamber products of combustion which are substantially neutral to metal to be heated in said work chamber, said last mentioned means comprising a combustion chamber, burner means for supplying a combustible mixture of fuel and air having a high deficiency of air to said combustion chamber, the walls of said combustion chamber being composed of a refractory material having high heat insulating properties, whereby the inner surface of said chamber will be maintained substantially at the combustion temperature of said mixture, said combustion chamber having an outlet port of restricted cross-sectional area, whereby a substantially uniform pressure of the products of combustion will be maintained in the combustion chamber, a conduit extending directly from said outlet port to said work heating chamber, said conduit being composed of a refractory material having high heat insulating properties and means for adding a hydrocarbon fuel to said products of combustion between said outlet port and said work chamber.

3. In an industrial furnace, the combination of a work heating chamber, radiant heating means for said chamber, control means for said radiant heating means for maintaining a predetermined temperature in said work chamber, means for supplying to said work chamber products of combustion which are substantially neutral to metal to be heated in said work chamber, said last mentioned means comprising a combustion chamber, burner means for supplying a combustible mixture of fuel and air having a high deficiency of air to said combustion chamber, the walls of said combustion chamber being composed of a refractory material having high heat insulating properties, whereby the inner surface of said chamber will be maintained substantially at the combustion temperature of said mixture, said burner means being disposed in said combustion chamber in a position to discharge against a wall of the chamber, said combustion chamber having an outlet port of restricted cross-sectional area and said restricted area being restricted relative to the cross-sectional area of said combustion chamber and the capacity of said burner means.
that a positive pressure of the products of combustion of the order of at least 0.1 inches of water will be maintained in said combustion chamber, and a conduit extending directly from said outlet port to said work heating chamber.

4. In an industrial furnace, the combination of a work heating chamber, radiant heating means for said chamber, control means for said radiant heating means for maintaining a predetermined temperature in said work chamber, means for supplying to said work chamber products of combustion which are substantially neutral to metal to be heated in said work chamber, said last mentioned means comprising a combustion chamber, burner means for supplying a combustible mixture of fuel and air having a high deficiency of air to said combustion chamber, the walls of said combustion chamber being composed of a refractory material having high heat insulating properties, whereby the inner surface of said combustion chamber will be maintained substantially at the combustion temperature of said mixture, said burner means being disposed in said combustion chamber in a position to discharge against a wall of the chamber, said combustion chamber having an outlet port of cross-sectional area so restricted relative to the cross-sectional area of said combustion chamber and the capacity of said burner means that a positive pressure of the products of combustion of the order of at least 0.1 inches will be maintained in said combustion chamber, a conduit extending directly from said outlet port to said work heating chamber, said conduit being composed of a refractory material having high heat insulating properties, and means for adding a hydrocarbon fuel to said conduit.

5. In an industrial furnace, the combination of a work heating chamber, radiant heating means for said chamber, control means for said radiant heating means for maintaining a predetermined temperature in said work chamber, a combustion chamber having refractory walls composed of a material having high heat insulating properties, burner means for the combustion of a mixture of fuel and air having a substantial deficiency of air for complete combustion, whereby hot combustion products are produced in said combustion chamber, a conduit extending directly from said combustion chamber into said work heating chamber for conducting said hot combustion products into said work heating chamber, said conduit having refractory walls whereby to prevent substantial cooling of said products in passing therethrough.

6. In an industrial furnace, the combination of a work heating chamber, radiant heating means for said chamber, control means for said radiant heating means for maintaining a predetermined temperature in said work chamber, a combustion chamber having refractory walls composed of a material having high heat insulating properties, burner means for the combustion of a mixture of fuel and air having a substantial deficiency of air for complete combustion, whereby hot combustion products are produced in said combustion chamber, a conduit extending directly from said combustion chamber into said work heating chamber for conducting said hot combustion products into said work heating chamber, said conduit having refractory walls whereby to prevent substantial cooling of said products in passing therethrough, and means for adding a lithium containing gas to said products of combustion.

7. In an industrial furnace, the combination of a work heating chamber, radiant heating means for said chamber, control means for said radiant heating means for maintaining a predetermined temperature in said work chamber, a combustion chamber having refractory walls composed of a material having high heat insulating properties, burner means for the combustion of a mixture of fuel and air having a substantial deficiency of air for complete combustion, whereby hot combustion products are produced in said combustion chamber, a conduit extending directly from said combustion chamber into said work heating chamber for conducting said hot combustion products into said work heating chamber, said conduit having refractory walls whereby to prevent substantial cooling of said products in passing therethrough, and means for adding an unreacted hydrocarbon fuel to said products of combustion in said conduit.

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