

July 29, 1958

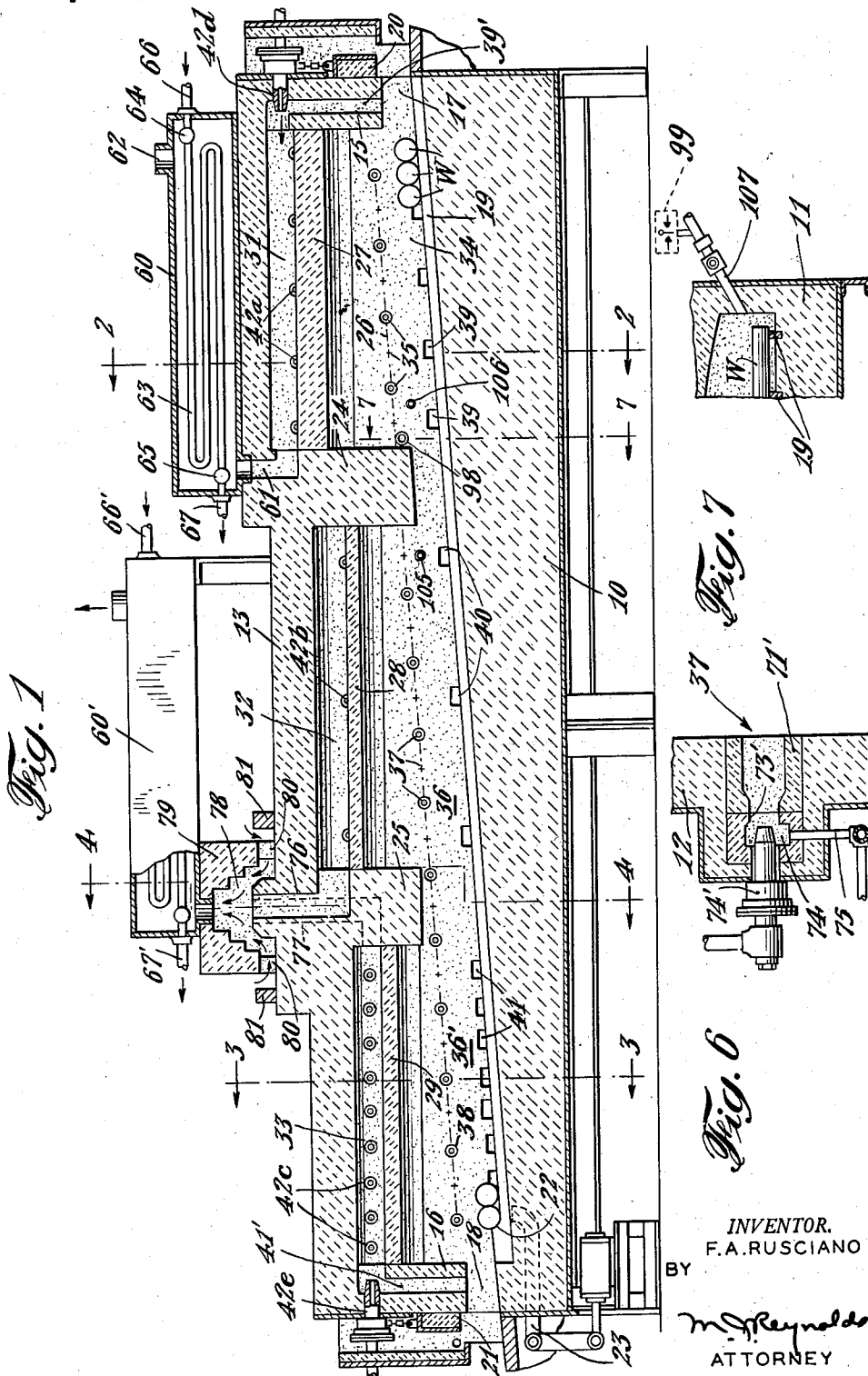
F. A. RUSCIANO

2,845,260

NEUTRAL HEATING WITH CONTROLLED PREHEAT

Filed April 9, 1954

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July 29, 1958

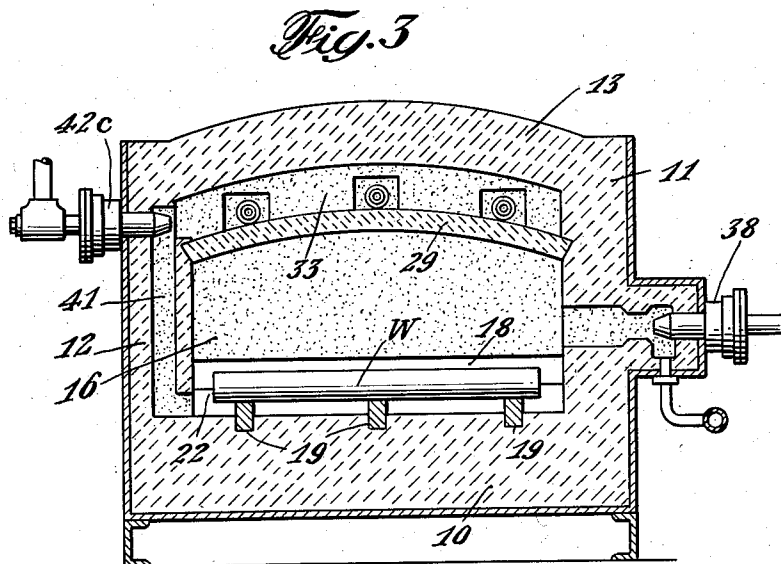
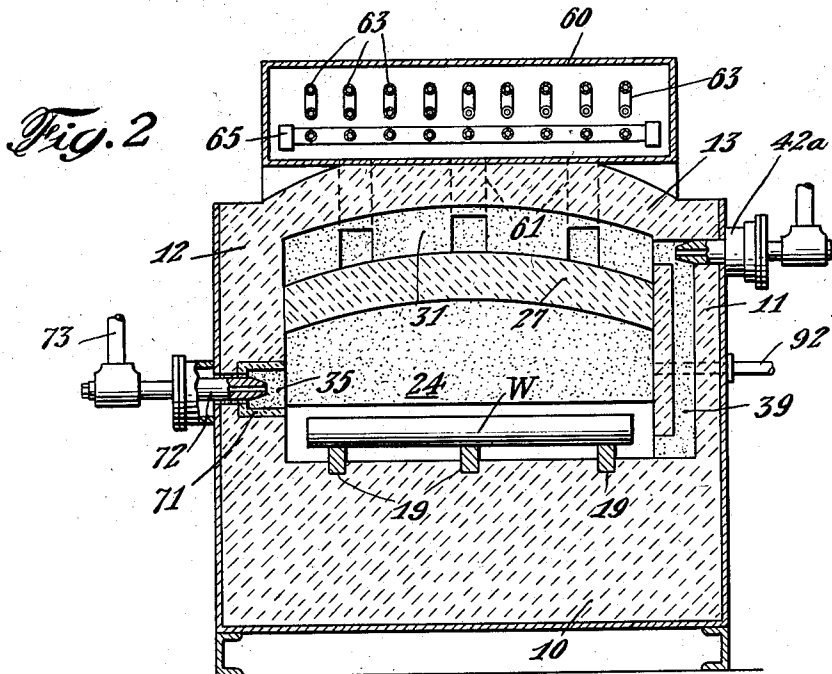
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NEUTRAL HEATING WITH CONTROLLED PREHEAT

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4 Sheets-Sheet 2



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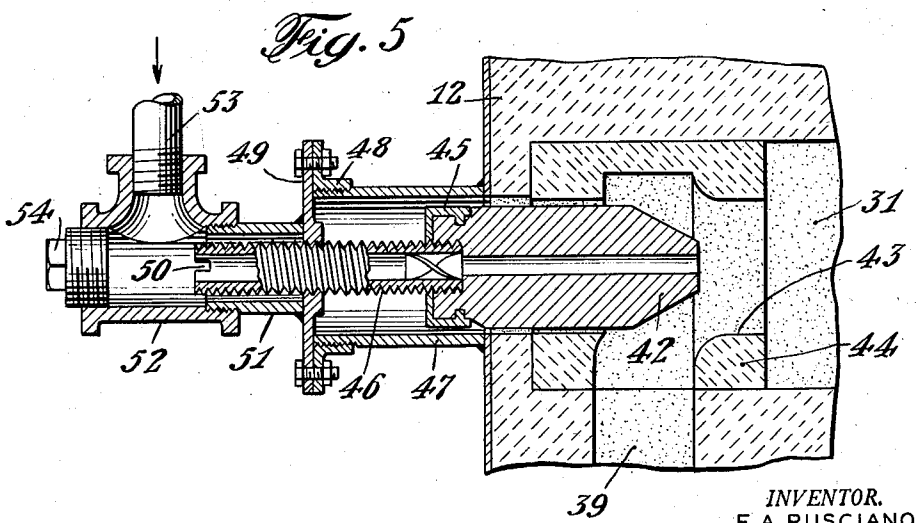
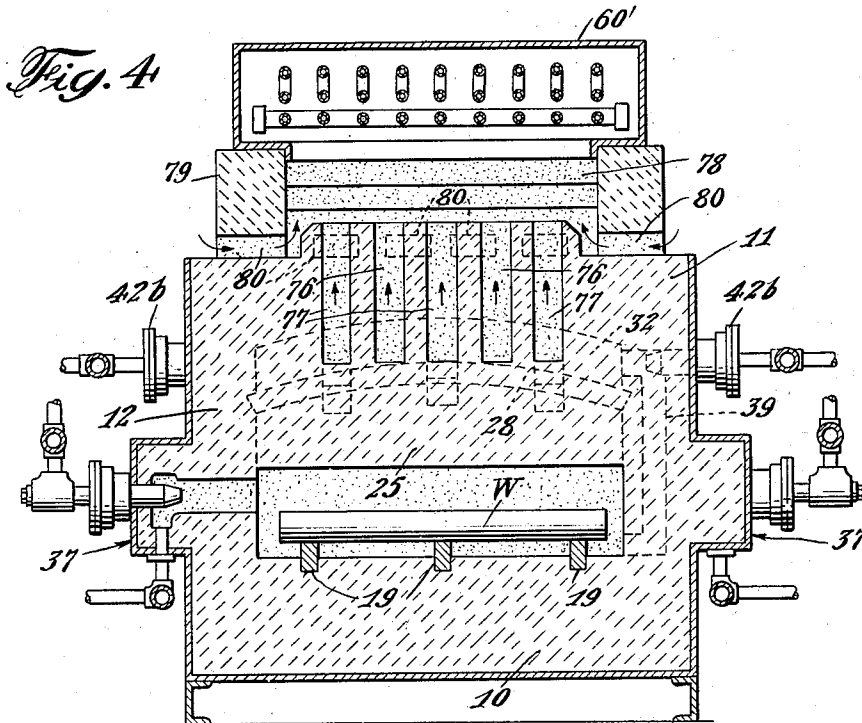
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4 Sheets-Sheet 3



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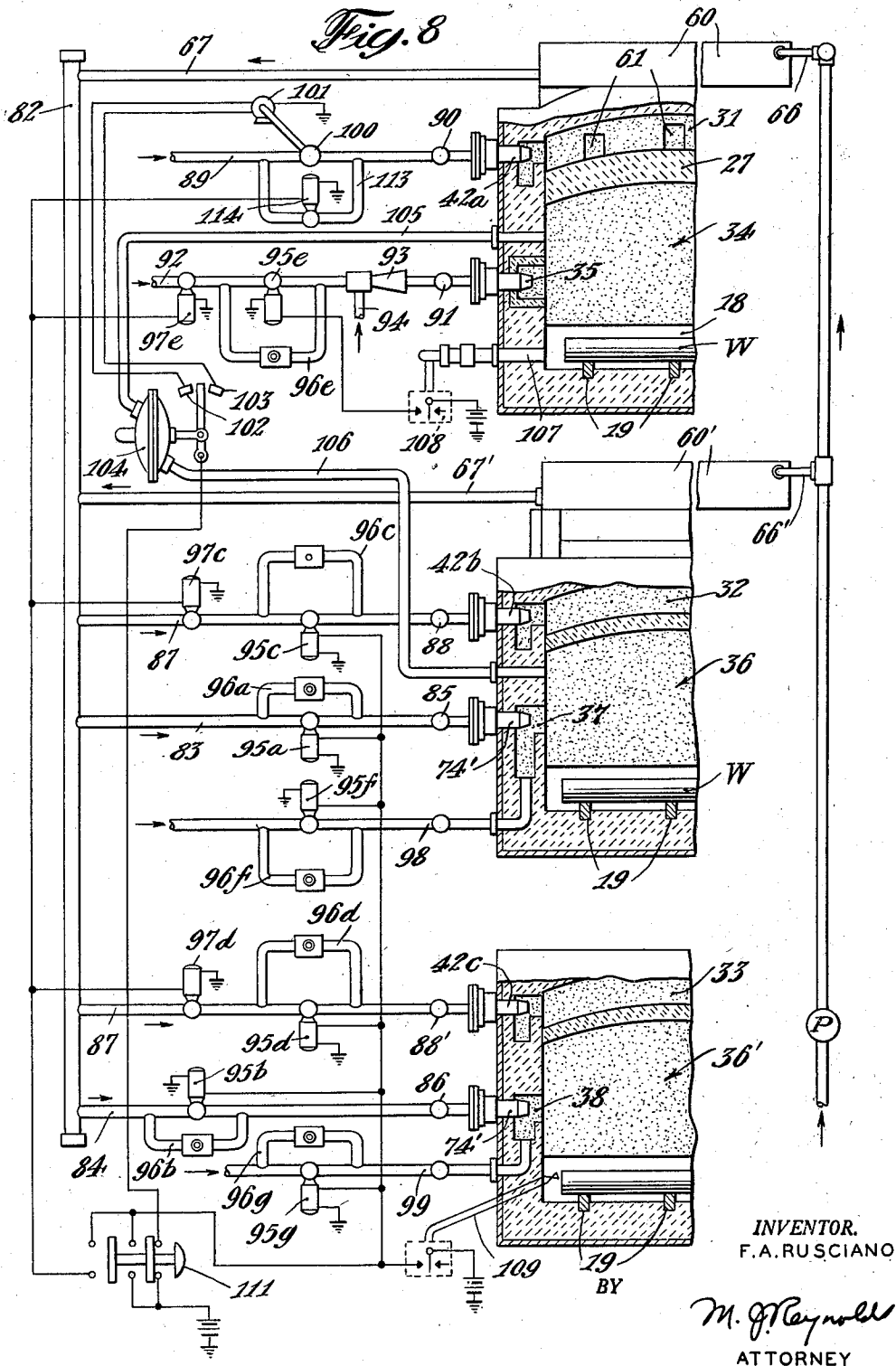
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NEUTRAL HEATING WITH CONTROLLED PREHEAT

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2,845,260

NEUTRAL HEATING WITH CONTROLLED PREHEAT

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Application April 9, 1954, Serial No. 422,074

17 Claims. (Cl. 266—5)

This invention relates to a method for producing rapid and efficient heating of metals to elevated temperatures under substantially non-scaling conditions and to a furnace structure by which such method may be practiced.

In an application Ser. No. 347,716, filed April 9, 1953, and entitled "Method and Apparatus for Producing Controlled Furnace Atmospheres" a method is disclosed for producing a non-scaling atmosphere in a direct fired furnace in which the metal being heated is subjected directly to the products of the furnace burners. Briefly, this method comprises adjusting the air-fuel ratio of the burners so that the reaction products, when the reactions are carried to substantial completion, will have a CO_2/CO and $\text{H}_2\text{O}/\text{H}_2$ ratio of such value that the sum thereof is equal to unity. The reactions resulting from such mixture, while providing an ideal non-oxidizing atmosphere for the furnace, release a relatively small percentage of the available B. t. u. of the fuel, of the order of 25%, and therefore provide a low heating rate and a restricted upper temperature limit. In the process of the aforesaid application, these limitations are overcome by the subsequent combustion of this atmosphere gas externally of the work chamber and out of contact with the work but in heat transfer relation thereto.

The present invention utilizes the principal features of the aforesaid application, one of its objects being to increase the heating rate over that obtainable with the previous process.

Another object is to increase the operating efficiency of the aforesaid process and to decrease the cost of the furnace equipment employed in the practice thereof.

A still further object is to provide a novel furnace structure for the production of scale-free or substantially scale-free heating of metals.

Other objects and advantages will appear as the description proceeds.

In accordance with the present invention the heating of the metal at elevated temperatures, that is, from a temperature in the range from about 1000° F. to 1500° F., up to the desired final temperature, which may be as high as 2500° F., is carried out in the neutral combustion atmosphere disclosed in the aforesaid application for patent, and the rich neutral atmosphere gas so employed is subsequently combusted with additional air in a combustion chamber disposed externally of the high temperature heating zone but in heat transfer relation thereto, as disclosed in said application. The heating rate and heating efficiency of this arrangement is somewhat less than that of a direct fired furnace in which the fuel is combusted to substantial completion in the work heating chamber due to the losses inherent in the conduction of heat from the external combustion chamber to the work treating chamber. The present invention eliminates this efficiency differential over a large portion of the heating cycle by conducting the initial heating at the maximum permissible non-scaling rate up to the 1000° F. to 1500° F. range, in a substantially completely combusted atmosphere, that is, a combustion at-

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mosphere in which the CO_2/CO ratio approaches infinity. In this initial heating operation the temperature of the initial heat zone should be controlled so as to prevent the surface of the metal from attaining a temperature appreciably above the recited range for any substantial period. In other words, a balance should be maintained between the rate of heat absorption by the surface of the work and the rate of heat diffusion into the body of the work whereby the surface temperature will be retained substantially at but not above that at which material scaling occurs. When this balance is just maintained, for instance, by control of the quantity of combustible mixture supplied to the initial heating chamber, the preheating will be effected at the maximum permissible non-scaling rate.

In many heating operations, as for instance, in the heating of billets, bar stock and other heavy pieces for mechanical working, such as rolling, piercing, swaging, forging, or the like, a light surface oxidation or slight scale may be entirely unobjectionable, or even desired, and in such cases the initial heating in the oxidizing combustion atmosphere, if not prolonged, may be carried up to surface temperatures of about 1500° F. or, in the case of some alloy steels, up to as high as 1700° F. Thus, the invention contemplates an initial heating of metal up to a predetermined surface temperature in the range between 1000° F. and 1700° F. in a combustion atmosphere which at higher surface temperatures would be highly oxidizing to the metal, followed by a heating to final temperature in either a non-scaling or a reducing atmosphere, the initial heating range depending upon the nature of the metal, the rate of heating and the amount of allowable oxidation of the work when it attains its final temperature. Above this initial heat range it is necessary, in order to prevent further scaling, to decrease the oxygen content of the air-fuel mixture to approximately 50% of that required for complete combustion so as to produce an atmosphere in which the ratio of CO_2 to CO will be in the range from about 0.3 to 0.6, depending on the temperature, and in which the sum of the CO_2/CO and $\text{H}_2\text{O}/\text{H}_2$ ratios will be equal substantially to unity. If it is desired to reduce some of the scale produced in the initial heating, it is necessary to use somewhat less air in the mixture employed to produce the final heating atmosphere.

The invention is described herein with particular reference to a continuous furnace but it is equally applicable to other types of furnaces. In the present embodiment the furnace comprises a linear or straight-through heating chamber in which the work to be heated passes from one end to the other. This chamber is divided into three heating zones, the first extending from the charging opening to a point at which the work will have attained, in a prescribed time, a temperature in the 1000° to 1700° F. range, and the second and third zones extending in succession from the end of the first zone to the discharge end of the chamber. The first zone is provided with a high temperature atmosphere obtained by the substantially complete combustion of a fuel and air mixture in burners extending into this zone, although the combustion could equally well be effected in separate combustion chambers in direct communication with this zone. The second zone is in continuous free communication with the first zone and the third zone is in similar relation to the second zone, one merging into the other and forming part of the same heating chamber. The second and third zones are each provided with a hot atmosphere produced by the reaction or combustion of a fuel and air mixture having a sufficient deficiency of air required for complete combustion to render the atmosphere non-scaling to the work at the elevated temperature attained in these zones. This non-scaling atmosphere gas is also generated in

burners directly associated with the second and final heating zone. Since the air-gas mixture here employed is at the lower end of the exothermic range, it is desirable to add some supplemental heat to the mixture in order to insure completion of the reactions prior to contact of the reaction products with the work. Various means for supplying this supplemental heat may be employed, as disclosed in the aforesaid application, but in the present embodiment it is obtained by employing the exhaust gases from the furnace to heat the air supplied to the burners of the two final heating zones.

The second heating zone serves to heat the metal from the preheat range to an intermediate temperature, for example, 2000° F., which is still considerably below the final work temperature desired, say 2350° F. The temperature head required in the second or intermediate temperature at a prescribed rate is, of course, lower than the temperature head required to heat the metal from the intermediate to the final temperature at the same heating rate. It has been found with a given total quantity of heat release in the second and third zones that a considerably faster overall heating rate in those zones can be obtained by dividing this total heat release in such a way as to produce a materially higher temperature head in the final zone over that maintained in the intermediate zone, and the invention contemplates effecting this result in a manner which will maintain a neutral atmosphere in both zones.

The neutral or non-scaling atmosphere produced in the second and third zones, because of its large deficiency in oxygen, produces a relatively small amount of heat, approximately 20% to 30% of that produced in the initial zone, per unit of fuel. This atmosphere therefore contains an additional 70% to 80% of available heat. This potential heat is converted into sensible heat by completing the combustion thereof with additional air in a second combustion chamber separated from the work heating chamber by a relatively thin partition of high heat conductivity.

The invention further includes means for segregating the atmospheres produced in the initial and intermediate heating zones and in cooling the exhaust gas from the initial zone, when necessary, to a suitable temperature for passage through an alloy heat exchanger, as will fully appear from the description of the accompanying drawings, in which:

Fig. 1 is a central vertical longitudinal section of a furnace embodying the features of the invention;

Fig. 2 is a vertical transverse section of the furnace taken on the line 2—2 of Fig. 1;

Fig. 3 is a vertical transverse section taken on the line 3—3 of Fig. 1;

Fig. 4 is a vertical transverse section taken on the line 4—4 of Fig. 1;

Fig. 5 is a detailed sectional view of an air inlet nozzle employed for the secondary combustion chamber;

Fig. 6 is a detailed sectional view of one type of burner employed in the furnace shown;

Fig. 7 is a fragmentary sectional view taken on the line 7—7 of Fig. 1; and

Fig. 8 is a schematic view of the piping and valving arrangement for the supply of air and fuel to the furnace.

Reference will first be made to Figs. 1 and 2 in which a continuous furnace of the gravity or roll-down conveyor type is shown. The furnace is composed of refractory brickwork and includes an inclined floor 10, side walls 11 and 12, an arched roof 13 and end walls 15 and 16. The end wall 15 is provided with a restricted passageway forming a charging slot 17 and end wall 16 has a similar restricted passageway forming a discharge slot 18, the work W, shown as round bar stock, being conveyed from the charging slot to the discharge slot by gravity, rolling upon the spaced rails 19, composed of a material, such as silicon carbide, which is capable of withstanding both the load and the temperature. In the

case of flat stock, suitable pusher mechanism may be employed to force the work along the rails 19. Other forms of conveyance for the work may be provided, such as a belt or chain conveyor, depending on the nature of the work and the temperature to which it is to be heated. The conveyor mechanism forms no part of the present invention, except that it is necessary to provide some convenient means for transporting the work through the heating chamber. As shown in Fig. 1, the bars come to rest against a shouldered portion 22 of the rails 19 and are raised over this shoulder for discharge through the slot 18, by pneumatically operated levers 23.

The charging and discharging slots or passageways 17 and 18 are provided with doors 20 and 21, respectively, adapted to be opened and closed by conventional mechanism, not shown.

A pair of depending bulkheads or partitions 24 and 25 depend from the arched roof 13, bulkhead 24, terminating below the centerline 26 of the burners which extend through the side walls 11 and 12, and above the floor or hearth 10 a distance only sufficient for the convenient passage of work therebeneath, so as to produce a restricted passage. A relatively thick supplemental arch 27 (Fig. 2) extends completely across the heating chamber between the bulkhead 24 and the front end wall 15, and a pair of relatively thin arched slabs 28, 29 (Figs. 1 and 3) extend completely across the heating chamber between the bulkheads 24, 25, and between bulkhead 25 and rear end wall 16, respectively. These supplemental arches are spaced from the main roof arch 13 to form the chambers 31, 32 and 33, the purpose of which will hereinafter appear. The supplemental arch 27 is composed of a good heat insulating refractory, whereas arches 28 and 29 are composed of a material having good heat conductivity and high temperature strength, such as silicon carbide.

The initial heat zone, indicated at 34, extends from the front end wall 15 to the bulkhead 24 and is provided, along the burner line 26, at each side of the furnace with a row of burners 35, those indicated by circles in Fig. 1 extending into the zone 34 through the side wall 11, and those indicated by crosses extending through the opposite side wall 12. The burners 35, as will more fully appear, are supplied with a mixture of fuel and air proportioned for substantially complete combustion of the fuel.

The intermediate heat zone 36 extends from the bulkhead 24 to the bulkhead 25 and is provided with a series of burners 37 extending through the side walls 11 and 12.

The final or high temperature heat zone 36' extends from the bulkhead 25 to the discharge slot 18 and is provided with a series of burners 38 extending through the side walls 11 and 12. Burners 37 and 38 are supplied separately with very rich mixtures of fuel and air proportioned somewhat differently, as will later appear, but of such ratio as to produce a non-scaling atmosphere in each of the zones 36 and 36'. The mixture, which will produce a combustion atmosphere which is just neutral, as stated, is one which on complete reaction will produce at atmosphere in which the sum of the CO₂/CO and H₂O/H₂ ratios is approximately one. The actual CO₂/CO and H₂O/H₂ ratios will vary with temperature, the respective values at 1500° F. both being about 0.5; at 1800° F. about 3.8 and 6.2; and at 2100° F. about 0.3 and 0.7. The proper air-fuel mixture for obtaining these ratios is largely independent of the operating temperature and is controlled primarily by the ratio of molecular carbon to hydrogen in the fuel. Thus a fuel having a C/H₂ molecular ratio of 0.75, such as propane (C₃H₈) will be restricted to approximately 54% of the oxygen required for complete combustion in order to achieve the above CO₂/CO and H₂O/H₂ ratios. With higher C/H₂ ratios, larger proportions of air may be employed. Substantially all industrial furnace fuels will have a C/H₂ ratio

between 0.5 and 1.5 and will produce the desired CO_2/CO and $\text{H}_2\text{O}/\text{H}_2$ ratios with an air deficiency of from 40% to 50%. Curves showing these relationships are disclosed in the aforesaid application.

The initial heat zone 34 is vented by means of a series of flues 39 extending from the floor level upwardly through each of the side walls 11 and 12 and terminating in the upper arch chamber 31. Zones 36 and 36' are likewise vented to the chambers 32 and 33 by means of flues 40 and 41, respectively. Each of the flues 39, 40 and 41 is provided at its upper end with a nozzle, such as 42 (Fig. 5), in proper relationship to the flue outlet to produce a suction effect in the flue for withdrawing the atmosphere gases from the heating chamber under controlled draft and thus at any desired rate depending on the velocity of the air so supplied and the adjustment of the nozzles relative to the ports. The nozzles provided for chamber 31 are designated 42a and those associated with chambers 32 and 33 are designated 42b and 42c, respectively. Referring to Fig. 5, the nozzle 42 is shown as having a conical end which may be adjusted relative to the port 43 extending into the chamber 31, 32 or 33, so as to regulate the effective port area. This nozzle is composed of a high temperature refractory, such as silicon carbide, and extends into a refractory block 44 of similar material, forming the flue outlet port 43. The nozzle is carried by an alloy metal cup 45 welded to an externally threaded pipe 46. A tube 47, welded to the shell of the furnace, carries a pipe flange 48 to which a plate 49 is bolted. The plate 49 has a central aperture in threaded engagement with the pipe 46, and the latter is slotted at 50 to receive a tool for turning the pipe to adjust the nozzle relative to the port in block 44. The outer end of the pipe 46 is enclosed in a tube 51, welded at one end to plate 49 and having a T connection 52 at the opposite end with the air conduit 53. A removable plug 54 permits access to the pipe 46 for the adjustment thereof.

The function of the nozzles 42a provided for the flue 39 is two-fold. First, they create the desired suction in the flues to control the pressure in zone 34, and secondly, they supply air to the chamber 31 to cool the exhaust gases to a temperature of approximately 2000° F. so that these gases may be passed through a prefabricated alloy heat exchanger 60 carried on the roof of the furnace. The heat exchanger is open to the chamber 31 by a group of passageways 61 and to the outer air by an outlet opening 62. A series of thin wall alloy tubes 63 are contained within the heat exchanger, extending between the headers 64 and 65. Cold air is admitted to header 64 by a conduit 66 and heated air is conducted from header 65 by one or more conduits, such as 67.

The burners 35 employed for zone 34 each comprise a burner block 71 of high heat-resisting refractory, such as silicon carbide, and a nozzle 72, air and gas, at suitable pressure, being supplied to the burner nozzle by a conduit 73 so as to admit the desired quantity of gas and air premixed in completely combustible proportions.

The burners 37 and 38 employed for zones 36 and 36', respectively, are shown in Fig. 6. They comprise an elongated burner block 71' of heat-resisting refractory having a recess 74 and an intermediate restriction 73'. Air under suitable pressure and at an elevated temperature is supplied to the burner by a nozzle 74' and gas at suitable pressure is supplied to the burner recess by a conduit 75. The relative quantities of air and gas are so regulated, as will later appear, to produce a non-oxidizing atmosphere in the zones 36 and 36'.

The air nozzles 42b and 42c provided for the flues 40 and 41 serve the dual purpose of controlling the pressure in zones 36 and 36' of the heating chamber and to supply air to the gases exhausted therefrom for the purpose of completing the combustion thereof in the arch chambers 32 and 33.

Each of the chambers 32 and 33 are vented by flues 76 and 77, respectively, which terminate above the furnace roof. These gases discharge into a wedge-shaped chamber 78, formed in a body of refractory brickwork 79, the narrow or restricted upper end of which is connected to the inlet of a heat exchanger 60' similar to heat exchanger 60. The chamber 78 is open to the air by passageways 80 in the base of the brickwork for the purpose of inducing cooling air into the exhaust gas stream to reduce the temperature thereof to enable these gases to be safely passed through the metal heat exchanger. Baffles 81 disposed opposite the passageways 80 are adjustable to control the amount of air so admitted. Cold air under pressure is admitted by conduit 66' to one end of the heat exchanger and heated air is extracted from the opposite end by conduit 67'.

The end walls 15 and 16 through which the restricted work loading and discharge passageways 17 and 18 extend are provided respectively with vents 39' and 41', each of which is also supplied with a suction producing nozzle, designated 42d and 42e, respectively. The particular purpose of these vents is to create a zone of reduced pressure in the slots so as to reduce the flaming out of the furnace gases when the doors 20 or 21 are opened. This is particularly important at the discharge end since the atmosphere in the final heat zone 36', because of its high oxygen deficiency, will burn vigorously if it is permitted to vent through the door opening. The zone of reduced pressure formed in the slot 18 acts to restrict this venting when the door is open and further prevents burning around the edges of the door when it is closed. The suction effect of nozzles 42d and 42e may be adjusted, if desired, to create an inward flow of air as distinguished from an outward flow of furnace atmosphere gases.

Reference will now be had to Fig. 8 for a disclosure of the valving and piping arrangement of the furnace. The air passed through the heat exchangers 60 and 60' under suitable pressure is supplied to the inlet conduits 66 and 66' by a pump or blower P and the size of these heat exchangers is assumed to be sufficient to heat this air to a temperature between 500° F. and 1000° F. This heated air is supplied by conduits 67 and 67' to a manifold 82 and fed therefrom to the conduits 83 and 84 leading to the manifolds 85 and 86 for supplying pressurized heated air to the nozzles 74' of burners 37 and 38 of the intermediate and final heat zones 36 and 36', respectively. Conduits 87 and 87' also convey this heated air to nozzles 42b and 42c of arch chambers 32 and 33 by way of manifolds 88 and 88'. Nozzles 42a of arch chamber 31 are supplied with unheated pressurized air by conduit 89 and manifold 90. Unheated air is also supplied to the burners 35 of the initial heat zone 34 by a manifold 91 fed from a conduit 92 containing a venturi air-gas mixer 93 by which gas from a zero pressure line 94 is induced into the air stream in such proportion as to be completely combustible at the burners 35. Conduits 83, 84, 87, 87' and 92 are provided with normally open electric valves 95a, 95b, 95c, 95d and 95e, respectively, by-passed by orificed conduits 96a, 96b, 96c, 96d and 96e, respectively. Conduits 87, 87' and 92 are also provided with a second normally open electric valve 97c, 97d, 97e, respectively. Conduit 89 has a rotary valve 100 therein operated to open and closed position by a two-directional motor 101 in circuit with contacts 102, 103 of a differential pressure regulator 104 having pressure tubes 105 and 106 extending from opposite sides of a spring-biased diaphragm to the zones 34 and 36, respectively, of the heating chamber, at points adjacent to the bulkhead 24. The purpose of this differential pressure regulator will appear hereinafter.

Electric valve 95e in the air conduit for the oxidizing burners 35 is controlled by a radiation type thermocouple 107 (Fig. 7) which sights directly upon the work W at a point in zone 34 adjacent to the bulkhead 24 and serves

to actuate the contacts 108, to close valve 95e whenever the surface of the work in the initial heat zone attains its prescribed maximum temperature in this zone, thereby placing the burners 35 on a reduced air and fuel supply, as determined by the orifice in the by-pass line 96e.

Electric valves 95a to 95d in the air lines 83, 84, 87 and 87' and valves 95f and 95g in the fuel lines 98 and 99 of burners 37 and 38, respectively, are controlled by a pyrometer 109 in the final heat zone 36', when the prescribed maximum temperature is attained in this zone, thus placing burners 37 and 38 on low fire and simultaneously reducing the air supply to the secondary combustion air nozzles 42b and 42c proportionally. Fuel valves 95f and 95g are by-passed by orificed lines 96f and 96g, respectively.

Each of the valves 95a, 95b, 95c, 95d, 95f, 95g, and 97c to 97e may be closed by operation of a manual switch 111 to the left, for purposes which will subsequently appear. All of these valves close completely when energized with the exception of valves 97c and 97d which are adjusted so as to only partially close to thereby permit a low flow of air therethrough of a value somewhat less than that passed by by-passes 96c and 96d when the valves 95c and 95d are closed. The purpose of the arrangement will later be described.

As previously indicated, the venturi mixer 93 is adjusted to supply an air-fuel mixture to the burners 35 of such proportion as to enable the fuel to burn to substantial completion, that is, with a negligible amount of carbon monoxide and hydrogen in the products of combustion. This mixture produces, in zone 34, a high flame temperature and combustion products which at temperatures above the range from 1000° F. to 1700° F. would be highly scaling to steel. It therefore produces a zone of high heating capacity in which the initial heating of the work may be effected at the maximum non-scaling rate and at high efficiency. As previously stated, some scaling may occur within the specified temperature range but the rate of scaling is relatively slow and by suitably controlling the supply of fuel to this zone by the surface temperature reading pyrometer 107 so as to maintain this surface at the maximum safe temperature, the work may be brought up to the preheat temperature in the minimum period consistent with the restriction of the oxidation to a light scale formation. Where scale-free work is desired, the initial heat zone may be restricted to temperatures at the lower end of the recited range, although the subsequent heating in the intermediate zone in an atmosphere which is slightly reducing, as will presently appear, will eliminate any light scale formed in the initial heat zone. For many operations, for instance, in the rolling of billets, a slight scale is desired and for such purposes the time and temperature of heating in the initial zone can be adjusted to attain the desired scale.

The valves 95a and 95f for supplying air and fuel to burners 37 of the intermediate zone are adjusted so as to supply an air-fuel mixture to these burners which will produce reaction products having a high CO and H₂ content, sufficient to give the unity summation of the CO₂/CO and H₂O/H₂ ratios or lower. This mixture is not highly reactive and requires supplemental energy to carry the reactions to completion, thereby to eliminate soot formation and to produce the desired neutral ratios of the reaction products. This energy is supplied by the heated air which in addition to carrying the reactions to completion in the burner tunnel also increases the temperature of the reaction products. Thus, by providing air at a temperature between 500° F. and 1000° F. the temperature of the gases entering the heating chamber is correspondingly increased thereby augmenting the heating effect of the gaseous products on the work. This is an important consideration since the heat produced in the reactions themselves is relatively low in comparison with that generated by complete combustion of the fuel and an increase of a few hundred degrees in the tempera-

ture of this atmosphere represents a fairly large proportionate increase in its heating effect. The valves 96b and 96g for supplying air and fuel to the burners 38 of the final heat zone may also be adjusted so as to supply an air-fuel mixture to the burners 38 which will produce neutral or nonscaling reaction products. Thus burners 37 and 38 may both be supplied with a mixture which is just sufficiently deficient in oxygen to produce neutral reaction products. However, I have discovered that if the air-fuel ratio supplied to the final heat zone is increased slightly and the ratio supplied to the intermediate zone correspondingly decreased, while maintaining the total air and fuel supplied to the combined zones at the neutral ratio, a considerably higher heat rate in the combined zones may be obtained or the same heating rate maintained with a lower fuel consumption. Thus, if the neutral air-gas ratio for the fuel employed, for instance, natural gas, is approximately 5-1, representing a 50% air deficiency, then burners 37 of zone 36 may be operated with a slightly lower ratio having an air deficiency of between 50% and 60%, say 4.5-1, and burners 38 of zone 36' with a higher ratio having an air deficiency of between 40% and 50%, say 5.5-1. The 5.5-1 ratio would produce reaction products having a CO₂/CO and a H₂O/H₂ ratio with a summation in excess of unity and such products would be slightly oxidizing. On the other hand, the 4.5-1 ratio would produce reaction products having a CO₂/CO and H₂O/H₂ ratio summation of less than unity. Therefore, by passing a portion of the richer atmosphere from zone 36 into zone 36' for reaction with the burner products in zone 36', an atmosphere may be produced therein which will have the neutral or unit ratio summation. The heat generated in zone 36 by the lower air-gas ratio is substantially less than the 25% obtainable from a 5-1 or neutral ratio. However, the work temperature to be obtained in this intermediate zone is also low compared to the final temperature, and it is comparatively easy by use of heated air and by burning a portion of the rich reaction products to completion in the overarch chambers 32 to obtain a sufficiently high temperature differential in this zone to effect rapid heating of the work through its intermediate temperature range.

In zone 36', however, the work must attain its final temperature of, say, 2350° F., and in order that this be effected at a rapid rate it is necessary that a temperature be obtained in this zone several hundred degrees higher than in the intermediate zone. This higher temperature is obtained partly by the higher flame temperature obtainable with the higher than neutral air-gas ratio and partly by the secondary combustion in chamber 33 of the reaction products of burners 38 and those introduced into zone 36' from zone 36. Actual field tests have shown that the use of an air-gas ratio less than the neutral ratio in the intermediate zone with a proportionately greater than neutral ratio in the final zone increases the overall heating rate in the order of 10% and permits higher final work temperatures to be obtained.

Referring again to Fig. 8, the air line valves 95a to 95d will supply an aggregate amount of air sufficient to burn to completion the total amount of gas supplied by valves 95f and 95g. Approximately 50% of this air will be supplied by valves 95a and 95b in the lines to burners 37 and 38 and 50% by valves 95c and 95d which supplies the air for secondary combustion through nozzles 42b and 42c. When valves 95a to 95c, 95f and 95g are closed under control of the pyrometer 109 upon attainment of a predetermined maximum temperature in zone 36', burners 37 and 38 are supplied with a proportionately reduced amount of air and fuel by the by-passes 96a and 96b. A proportional reduction in the air supplied to the nozzles 42b and 42c is obtained through by-passes 96c and 96d, respectively.

It is essential that no material intermixing of the gases in zones 34 and 36 occur, or at least that it be confined to that region of the chamber adjacent to the bulkhead

24, where the work temperature is not materially above that attained in the initial heat zone and therefore still resistant to scaling in the atmosphere formed by the inter-mixing of small amounts of the atmosphere of zone 34 with that of zone 36.

However, in order to prevent the flow of the atmosphere of zone 34 into zone 36, a number of precautions may be taken. The arrangement of the bulkhead 24 restricts such flow to a relatively shallow passage, and since the rich atmosphere admitted beneath the bulkhead is of a somewhat lower temperature than that in zone 34, this richer gas has a greater tendency to occupy this level of the heating chamber than the hotter more oxidizing gas of zone 34, pressures in the two areas being considered equal. Also, isolation of the oxidizing atmosphere to its zone 34 is assured by maintaining a pressure in zone 34 of a few thousandths of an inch lower than that maintained in zone 36. It will also be understood that a slight positive pressure, of the order of 0.01 inch, is maintained in the entire heating chamber.

The relative pressures in the two zones is maintained by the controlled suction effect of the nozzles 42a of zone 34 and nozzles 42b of zone 36. The amount of air required to complete the combustion of the gases vented from zone 36 is fixed by the air-fuel ratio supplied to the burners 37 and the proportion of the reaction products to be withdrawn from zone 36 through the vents 40. With the volume of this air so fixed, the suctional effect produced thereby is determined by the adjustment of the nozzles 42b relative to the ports 43, so as to withdraw the desired quantity of reaction products. The remainder of the reaction products pass from zone 36 either into zone 34 or zone 36', the combined venting effect of zone 36 being such as to maintain a positive pressure of about 0.01 inch in this zone. The volume of air supplied to the nozzles 42a of chamber 31 is approximately determined by the desired cooling of the completely combusted gases vented from zone 34 in order to bring these gases to a sufficiently low temperature to permit them to be safely passed through the heat exchanger 60. With the air supply so determined, the nozzles 42a are adjusted to also provide a pressure of about 0.01 inch in zone 34. The slight pressure differential desired between zones 36 and 34 is then automatically controlled by slightly increasing or decreasing the air supply to the nozzles 42a to thereby increase or decrease the suctional effect of this air on the flues 39. With the tubes 105 and 106 of pressure regulator 104 connected to opposite sides of the bulkhead 24, the diaphragm of the regulator 104 will be slightly spring-biased so that the switch blade 112 will be on contact 103 when the pressure differential in zones 34 and 36 decreases below the desired amount, contact 102 being made when the pressure differential increases above this predetermined amount. Motor 101 will therefore rotate the valve 100 to increase or decrease the air supply to the nozzles 42a in such manner as to lower or raise the pressure in zone 34 to reestablish the desired pressure relationship.

It is obvious that if it should be necessary to stop the movement of work through zone 34 for any appreciable period with a portion of the load still in this zone, such work might become undesirably scaled. In order to avoid scaling under such conditions the following procedure may be employed. First, the entrance and exit doors 20 and 21 are closed to isolate the furnace chamber from the external atmosphere. Thereafter, the switch 111 is moved to the left to energize valves 95a to 95d, 95f, 95g, 97c, 97d and 97e. Valve 97e closes down the oxidizing burners 35 completely. Valves 95a, 95b, 95f and 95g place the zones 36 and 36' on reduced air and fuel supply, and valves 97c and 97d, which only partially close, reduce the air supply to the nozzles 42b and 42c below that normally supplied by by-passes 96c and 96d thereby decreasing the normal "on-control" suction of these nozzles whereupon the pressure in zones 36 and 36'

tends to build up. With no gas being entered into zone 34 by its burners 35, the pressure in this chamber tends to decrease. Consequently the non-scaling atmosphere flows from zone 36 to zone 34 gradually flushing out and replacing the oxidizing atmosphere. This rich atmosphere in zone 34 will be burned in the arch chamber 31 by the air supplied by nozzles 42a and to insure that these combustion gases will not exceed the safe operating temperature of the heat exchanger 60, a surplus of air may be fed to the nozzles at this time by a by-pass 113 disposed around the motor operated valve 100 and containing a normally closed electric valve 114 in circuit with the manual switch 111. The pressure differential maintaining mechanism is disabled at this time by interruption of the power to motor 101 by the manual switch 111.

When it is desired to continue passage of work through the furnace, switch 111 is returned to the right restoring the furnace control to normal.

Under the above procedure the entire furnace is supplied with a non-scaling atmosphere under low fire and, therefore, the load may be left in the furnace during non-productive periods such as noon-hours or overnight. By adjusting the fuel supplied during this idling period to an amount just sufficient to overcome furnace radiation losses, the work may be kept substantially at final temperature during these idling periods whereby little or no time is lost in converting from the idling to the productive cycle. Since the heating cycle for large billets may be as long as three hours, this is an important saving in time.

In Fig. 8 the burners 37 and 38 are shown under the control of the single pyrometer 109. It is to be understood, however, that these burners may be arranged in groups, each group being provided with air and fuel supply valves, such as 95a, 95b, 95f and 95g, controlled by a separate pyrometer.

Obviously, numerous other modifications of the apparatus and the method of operation will occur to those skilled in the art without departing from the essential principles of the invention.

What is claimed is:

1. A furnace for the scale-free heating of metal comprising a heating chamber having an inlet opening at one end for the admission of work and an outlet opening at the opposite end for the removal of work, a partial barrier extending transversely across said chamber to form an initial heating zone and a succeeding heating zone having a restricted passageway therebetween only sufficient for the convenient passage of work from the initial zone to the succeeding zone, burners extending into said chamber in each of said zones, means for supplying fuel and air to the burners of said initial heating zone having a ratio to produce combustion products which are scaling to metal above a predetermined temperature, separate means for supplying fuel and air to the burners of the succeeding zone in a ratio to produce reaction products which are non-scaling to metal above said predetermined temperature, means responsive to the surface temperature of metal passing through said initial heating zone for controlling the supply of fuel and air to such zone to thereby restrict said surface temperature to a value below said predetermined temperature, separate venting means for each of said zones and means for controlling the relative rate of venting through said separate venting means.

2. A furnace for the scale-free heating of metal comprising a heating chamber having an inlet opening at one end for the admission of work and an outlet opening at the opposite end for the removal of work, a partial barrier extending transversely across said chamber to form an initial heating zone and a succeeding heating zone having a restricted passageway therebetween only sufficient for the convenient passage of work from the initial zone to the succeeding zone, burners extending into said chamber in each of said zones, means for supplying fuel

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and air to the burners of said initial heating zone having a ratio to produce combustion products which are scaling to metal above a predetermined temperature, separate means for supplying fuel and air to the burners of the succeeding zone in a ratio to produce reaction products which are non-scaling to metal above said predetermined temperature, means responsive to the surface temperature of metal passing through said initial heating zone for controlling the supply of fuel and air to such zone to thereby restrict said surface temperature to a value below said predetermined temperature, venting means for said succeeding heating zone independent of said initial heating zone, and means for precluding passage of combustion products from said initial heating zone into the succeeding heating zone.

3. A furnace for the scale-free heating of metal comprising a heating chamber having an inlet opening at one end for the admission of work and an outlet opening at the opposite end for the removal of work, a partial barrier extending transversely across said chamber to form an initial heating zone and a succeeding heating zone having a restricted passageway therebetween only sufficient for the convenient passage of work from the initial zone to the succeeding zone, burners extending into said chamber in each of said zones, means for supplying fuel and air to the burners of said initial heating zone having a ratio to produce combustion products which are scaling to metal above a predetermined temperature, separate means for supplying fuel and air to the burners of the succeeding zone in a ratio to produce reaction products which are non-scaling to metal above said predetermined temperature, means responsive to the surface temperature of metal passing through said initial heating zone for controlling the supply of fuel and air to such zone to thereby restrict said surface temperature to a value below said predetermined temperature, means for maintaining a predetermined positive pressure in said heating chamber, and means for maintaining the pressure in said initial heating zone at a value slightly below the pressure maintained in the succeeding heating zone, said last means including separate venting means for each of said chambers.

4. A furnace for the scale-free heating of metal comprising a heating chamber having an inlet opening at one end for the admission of work and an outlet opening at the opposite end for the removal of work, a partial barrier extending transversely across said chamber to form an initial heating zone and a succeeding heating zone having a restricted passageway therebetween for the passage of work from the initial zone to the succeeding zone, burners extending into said chamber in each of said zones, means for supplying fuel and air to the burners of said initial heating zone having a ratio to produce combustion products which are scaling to metal above a predetermined temperature, separate means for supplying fuel and air to the burners of the succeeding zone in a ratio to produce reaction products which are non-scaling to metal above said predetermined temperature, means responsive to the surface temperature of metal passing through said initial heating zone for controlling the supply of fuel and air to such zone to thereby restrict said surface temperature to a value below said predetermined temperature, independent vents for each of said zones, suction producing means in said vents, and means for controlling the suction means to cause a flow of reaction products into the initial heating zone from the succeeding heating zone.

5. A furnace for the scale-free heating of metal comprising a heating chamber having an inlet opening for the admission of work to be heated, an outlet opening for the discharge of work, means dividing said chamber into a plurality of intercommunicating successive heating zones including an initial heating zone and a final heating zone, burners extending into said chamber in each of said zones, means for supplying a mixture of air and

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fuel to the burners of said initial heating zone having a ratio to produce substantially complete combustion, separate means for supplying air and fuel to the burners of each succeeding zone having a large deficiency of air, means for venting the combustion products from said initial heating zone, separate means for venting the partially combusted products from each successive heating zone, a combustion chamber disposed in heat transfer relation to said final heating zone, said last mentioned venting means being in communication with said combustion chamber for passage of said partially combusted products thereinto, and means for supplying air to said combustion chamber to produce further combustion of said partially combusted products in said combustion chamber.

6. A furnace for the scale-free heating of metal comprising a heating chamber having an inlet opening for the admission of work to be heated, an outlet opening for the discharge of work, means dividing said chamber into a plurality of intercommunicating successive heating zones including an initial heating zone and a final heating zone, burners extending into said chamber in said initial heating zone, means for supplying a mixture of air and fuel to said burners having a ratio to produce substantially complete combustion, separate means for supplying to each succeeding zone hot combustion products of a mixture of fuel and air having a large deficiency of air, means for venting the combustion products from said initial heating zone, separate means for venting the partially combusted products from each successive heating zone, a combustion chamber disposed in heat transfer relation to said final heating zone, said last mentioned venting means being in communication with said combustion chamber for passage of said partially combusted products thereinto, and means for supplying air to said combustion chamber to produce further combustion of said partially combusted products in said combustion chamber.

7. A furnace for the scale-free heating of metal comprising a heating chamber having an inlet opening for the admission of work to be heated, an outlet opening for the discharge of work, means dividing said chamber into a plurality of intercommunicating successive heating zones including an initial heating zone and a final heating zone, burners extending into said chamber in each of said zones, means for supplying a mixture of air and fuel to the burners of said initial heating zone having a ratio to produce substantially complete combustion, separate means for supplying air and fuel to the burners of each succeeding zone having a large deficiency of air, means for venting the combustion products from said initial heating zone, separate means for venting the partially combusted products from each successive heating zone, a combustion chamber disposed in heat transfer relation to said final heating zone, said last mentioned venting means being in communication with said combustion chamber for passage of said partially combusted products thereinto, means for supplying air to said combustion chamber to produce further combustion of said partially combusted products in said combustion chamber, and means for maintaining a pressure differential between said initial heating zone and the next succeeding heating zone.

8. A furnace for the scale-free heating of metal comprising a heating chamber having an inlet opening for the admission of work to be heated, an outlet opening for the discharge of work, means dividing said chamber into a plurality of intercommunicating successive heating zones including an initial heating zone and a final heating zone, burners extending into said chamber in said initial heating zone, means for supplying a mixture of air and fuel to said burners having a ratio to produce substantially complete combustion, separate means for supplying to each succeeding zone hot combustion products of a mixture of fuel and air having a large deficiency of air, means

for venting the combustion products from said initial heating zone, separate means for venting the partially combusted products from each successive heating zone, a combustion chamber disposed in heat transfer relation to said final heating zone, said last mentioned venting means being in communication with said combustion chamber for passage of said partially combusted products thereinto, means for supplying air to said combustion chamber to produce further combustion of said partially combusted products in said combustion chamber, and pressure responsive means associated with the initial heating zone and the next successive heating zone for causing flow of partially combusted products from the latter zone to the former.

9. A furnace for the scale-free heating of metal comprising a heating chamber having an inlet opening for the admission of work, an outlet opening for the discharge of work, means dividing said chamber into a plurality of intercommunicating successive heating zones including an initial heating zone, an intermediate heating zone and a final heating zone, burners extending into said initial heating zone, means for supplying a mixture of fuel and air to said burners having a ratio to produce substantially complete combustion, means for supplying an atmosphere to said intermediate heating zone composed of hot combustion products of fuel and air having a deficiency of air between 50% and 60%, separate means for supplying an atmosphere to said final heating chamber composed of hot combustion products of fuel and air having a deficiency of air between 40% and 50% and separate venting means for the initial and final heating zones whereby the atmosphere in said intermediate heating zone will be drawn in part into said initial heating zone and in part into said final heating zone.

10. A furnace for the scale-free heating of metal comprising a heating chamber having an inlet opening for the admission of work, an outlet opening for the discharge of work, means dividing said chamber into a plurality of intercommunicating successive heating zones including an initial heating zone, an intermediate heating zone and a final heating zone, burners extending into said initial heating zone, means for supplying a mixture of fuel and air to said burners having a ratio to produce substantially complete combustion, means for supplying an atmosphere to said intermediate heating zone composed of hot combustion products of fuel and air having a deficiency of air between 50% and 60%, separate means for supplying an atmosphere to said final heating chamber composed of hot combustion products of fuel and air having a deficiency of air between 40% and 50%, separate venting means for the initial and final heating zones whereby the atmosphere in said intermediate heating zone will be drawn in part into said initial heating zone and in part into said final heating zone, and draft control means for each of said venting means.

11. A furnace for the scale-free heating of metal comprising a heating chamber having an inlet opening for the admission of work, an outlet opening for the discharge of work, means dividing said chamber into a plurality of intercommunicating successive heating zones including an initial heating zone, an intermediate heating zone and a final heating zone, burners extending into said initial heating zone, means for supplying a mixture of fuel and air to said burners having a ratio to produce substantially complete combustion, means for supplying an atmosphere to said intermediate heating zone composed of hot combustion products of fuel and air having a deficiency of air between 50% and 60%, separate means for supplying an atmosphere to said final heating chamber composed of hot combustion products of fuel and air having a deficiency of air between 40% and 50%, venting means for the final heating zone whereby the atmosphere in said intermediate heating zone will be drawn at least in part into said final heating zone, a combustion chamber disposed in heat transfer relationship to

said final heating zone, said venting means communicating with said combustion chamber for passage of the air deficient combustion products from said final heating zone into said combustion chamber, and means for supplying air to said combustion chamber to produce further combustion of said products therein.

12. A furnace for the scale-free heating of metal comprising a heating chamber having an inlet opening for the admission of work, an outlet opening for the discharge of work, means dividing said chamber into a plurality of intercommunicating successive heating zones including an initial heating zone, an intermediate heating zone and a final heating zone, burners extending into said initial heating zone, means for supplying a mixture of fuel and air to said burners having a ratio to produce substantially complete combustion, means for supplying an atmosphere to said intermediate heating zone composed of hot combustion products of fuel and air having a deficiency of air between 50% and 60%, separate means for supplying an atmosphere to said final heating chamber composed of hot combustion products of fuel and air having a deficiency of air between 40% and 50%, venting means for the final heating zone whereby the atmosphere in said intermediate heating zone will be drawn at least in part into said final heating zone, a combustion chamber disposed in heat transfer relationship to said final heating zone, said venting means communicating with said combustion chamber, and means including an air jet for inducing a flow of air deficient combustion products through said vent from said final heating chamber into said combustion chamber and serving to support combustion thereof in said combustion chamber.

13. A furnace for the scale-free heating of metal comprising a heating chamber having an inlet opening for the admission of work to be heated, an outlet opening for the discharge of work, means for dividing the chamber into a plurality of successive heating zones including an initial heating zone and a final heating zone, burners extending into said chamber in said initial heating zone, means for supplying a mixture of fuel and air to said burners having a ratio to produce substantially complete combustion, separate means for supplying to each succeeding zone hot reaction products of a mixture of fuel and air having an air deficiency of the order of 50%, means for venting said final heating zone independently of said initial heating zone, means for venting said initial heating zone independently of said final heating zone, and means for concurrently interrupting the supply of fuel and air to said burners and venting said final heating zone, at least in part, through said initial heating zone.

14. A furnace for the scale-free heating of metal comprising a heating chamber having an inlet opening for the admission of work to be heated, an outlet opening for the discharge of work, means for dividing the chamber into a plurality of successive heating zones including an initial heating zone and a final heating zone, burners extending into said chamber in said initial heating zone, means for supplying a mixture of fuel and air to said burners having a ratio to produce substantially complete combustion, separate means for supplying to each succeeding zone hot reaction products of a mixture of fuel and air having an air deficiency of the order of 50%, means for venting said final heating zone independently of said initial heating zone, means for venting said initial heating zone independently of said final heating zone, suction producing means in each of said venting means, and means for interrupting the supply of fuel and air to said burners and controlling said suction means to vent said final heating zone, at least in part, through said initial heating zone.

15. A furnace for the scale-free heating of metal comprising a work heating chamber, means for supplying air and fuel to said chamber with an excess of fuel for complete combustion of the order of 100%, a combustion chamber in heat transfer relation to said heating

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chamber, means for venting said heating chamber into said combustion chamber, means for supplying air to said combustion chamber for reaction therein with said vented products, a heat exchanger, means for venting the combustion products from said combustion chamber through said heat exchanger, means disposed between said combustion chamber and said heat exchanger for adding air to the vented combustion products to control the temperature thereof, and means for passing air through said heat exchanger out of contact with said combustion gases, said last means comprising said means for supplying air to said work heating chamber.

16. A furnace for the scale-free heating of metal comprising a work heating chamber, means for supplying air and fuel to said chamber with an excess of fuel for complete combustion of the order of 100%, a combustion chamber in heat transfer relation to said heating chamber, means for venting said heating chamber into said combustion chamber, means for supplying air to said combustion chamber for reaction therein with said vented products, means for venting the combustion products from said combustion chamber, means for cooling said combustion products and means for passing said cooled combustion products in heat transfer relation to said means for supplying air to said heating chamber.

17. A furnace for the scale-free heating of metal comprising a heating chamber, a restricted passageway ex-

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tending through a wall of said chamber for the passage of work, means for supplying an atmosphere for said furnace having a large deficiency in air for complete combustion, means for reducing combustion of said atmosphere with external air at said passageway including a vent in said passageway, suction means for said vent for producing a zone of reduced pressure in said passageway, said suction means including an air jet, a combustion chamber, and a passageway extending from said vent to said combustion chamber whereby the atmosphere withdrawn through said vent will be combusted with the air introduced by said jet.

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