Oct. 24, 1950 E. S. HARMAN ET AL 2,526,658

PROCESS FOR SMELTING IRON ORE

Filed Nov. 25, 1943 7 Sheets-Sheet 1

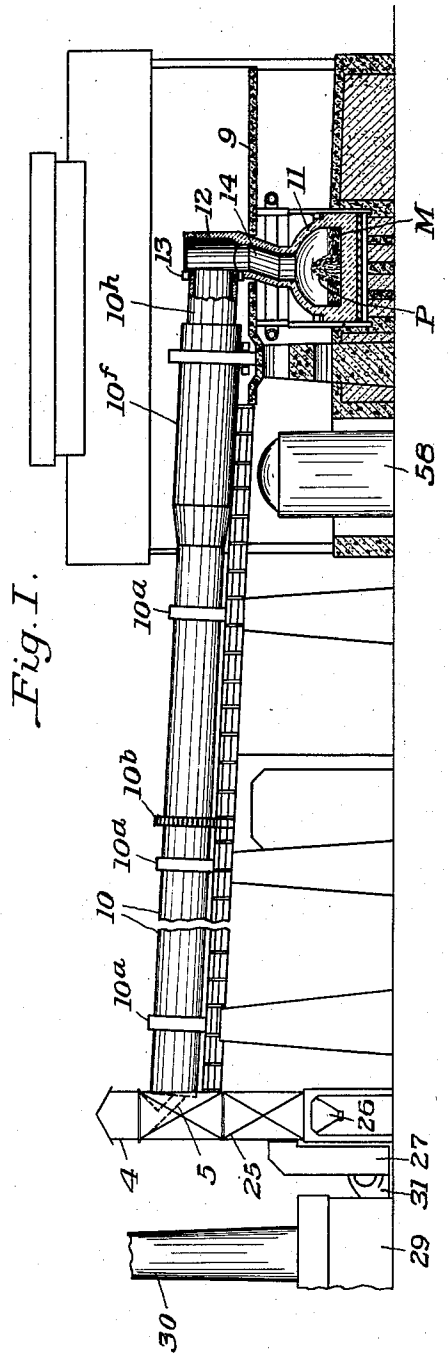


Fig. 1.

INVENTORS
Eugene S. Harman
Fred H. Loftus
by Christy, Parmelee and Strickland
attorneys

Oct. 24, 1950 E. S. HARMAN ET AL 2,526,658

PROCESS FOR SMELTING IRON ORE

Filed Nov. 25, 1943 7 Sheets-Sheet 2

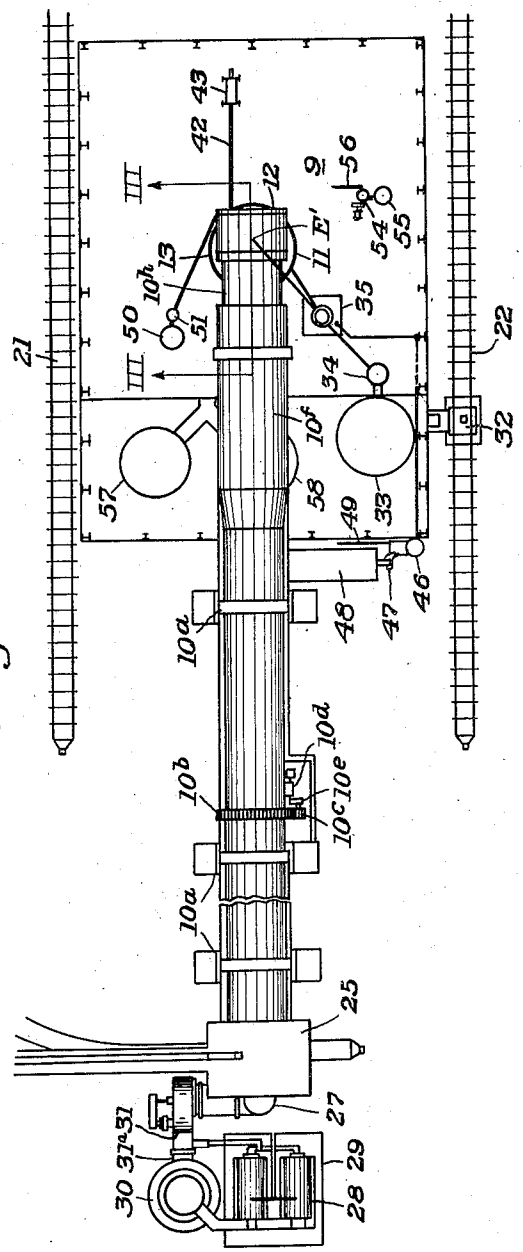


Fig. II.

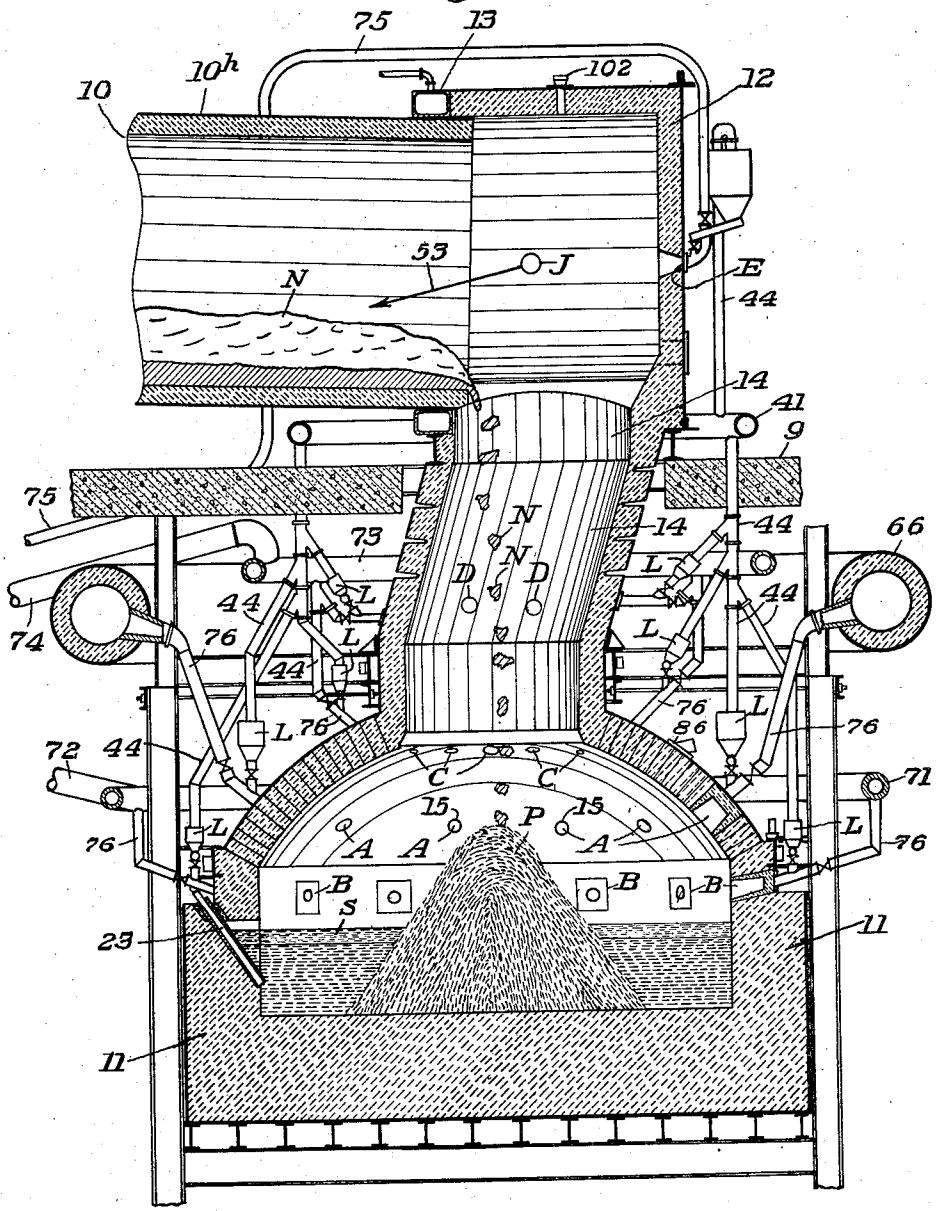
INVENTORS
Eugene S. Harman
Fred H. Loftus
by Christy, Parmelee and Strickland
attorneys

Oct. 24, 1950 E. S. HARMAN ET AL 2,526,658

PROCESS FOR SMELTING IRON ORE

Filed Nov. 25, 1943 7 Sheets-Sheet 3

Fig. III.



INVENTORS
Eugene S. Harman
Fred H. Loftus
by Christy, Parmelee and Strickland
attorneys

Oct. 24, 1950 E. S. HARMAN ET AL 2,526,658

PROCESS FOR SMELTING IRON ORE

Filed Nov. 25, 1943 7 Sheets-Sheet 4

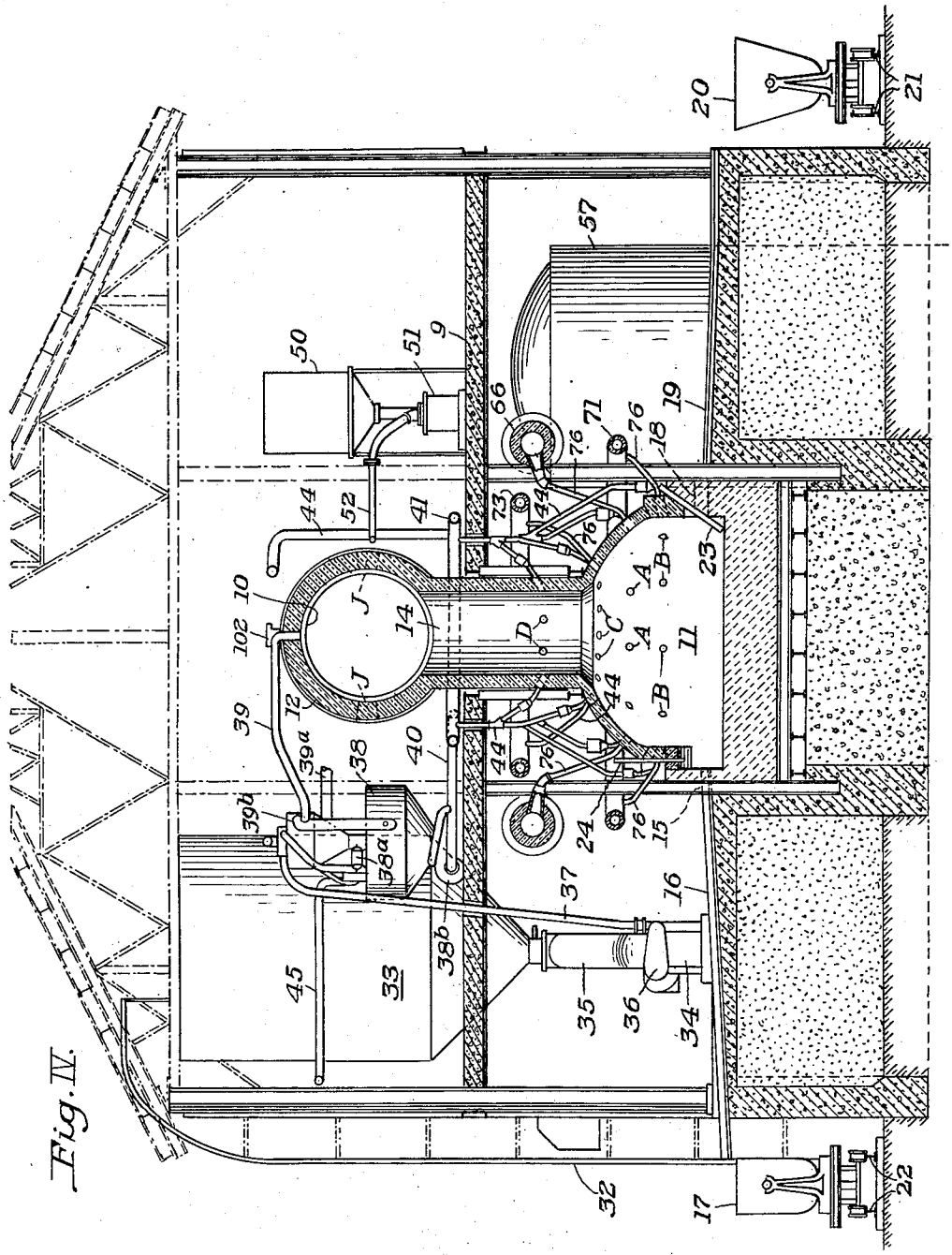


Fig. IV.

INVENTORS

Eugene S. Harman

Fred H. Loftus

by Christy, Parmelee and Strickland

attorneys

Oct. 24, 1950 E. S. HARMAN ET AL 2,526,658

PROCESS FOR SMELTING IRON ORE

Filed Nov. 25, 1943 7 Sheets-Sheet 5

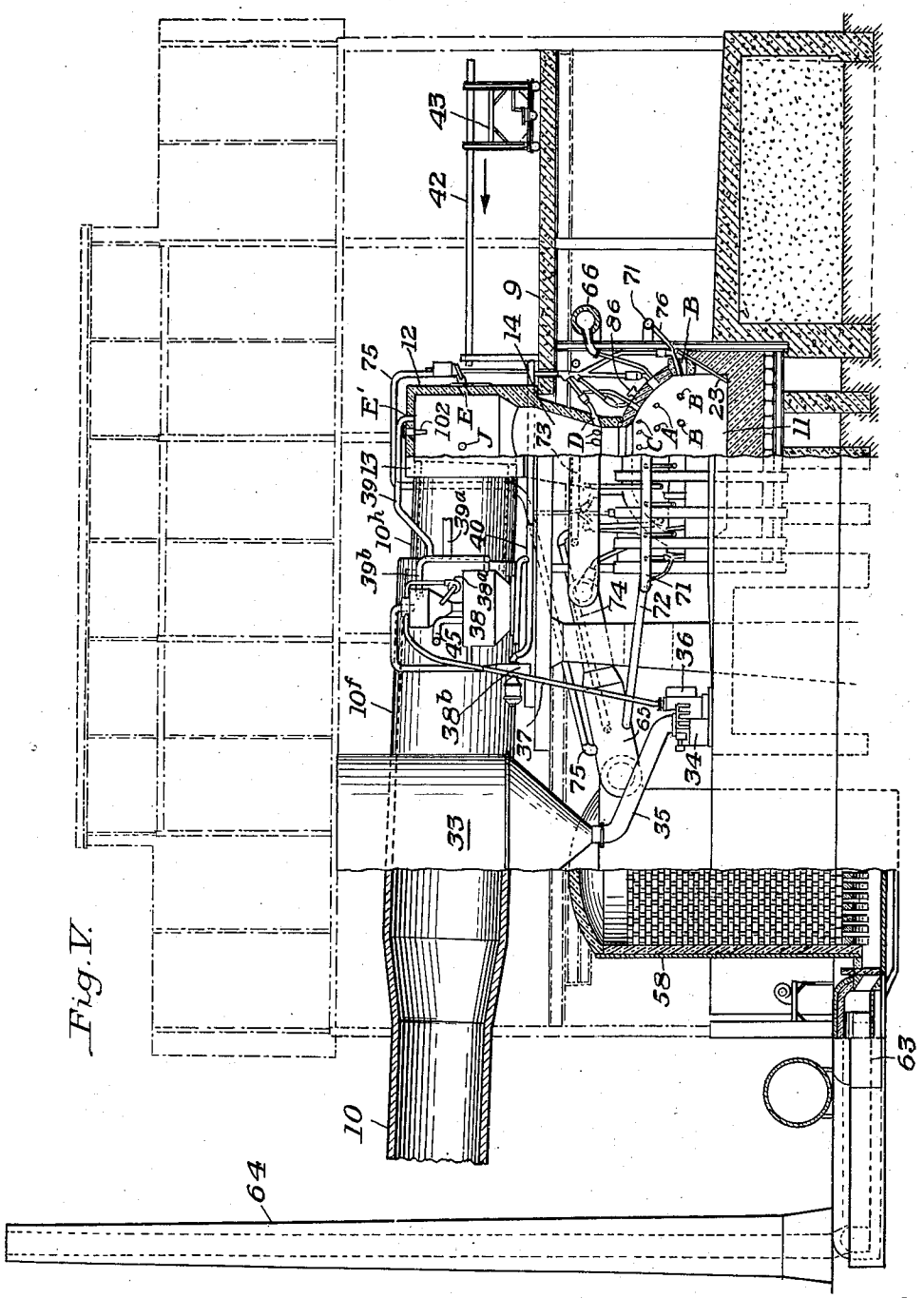


Fig. V.

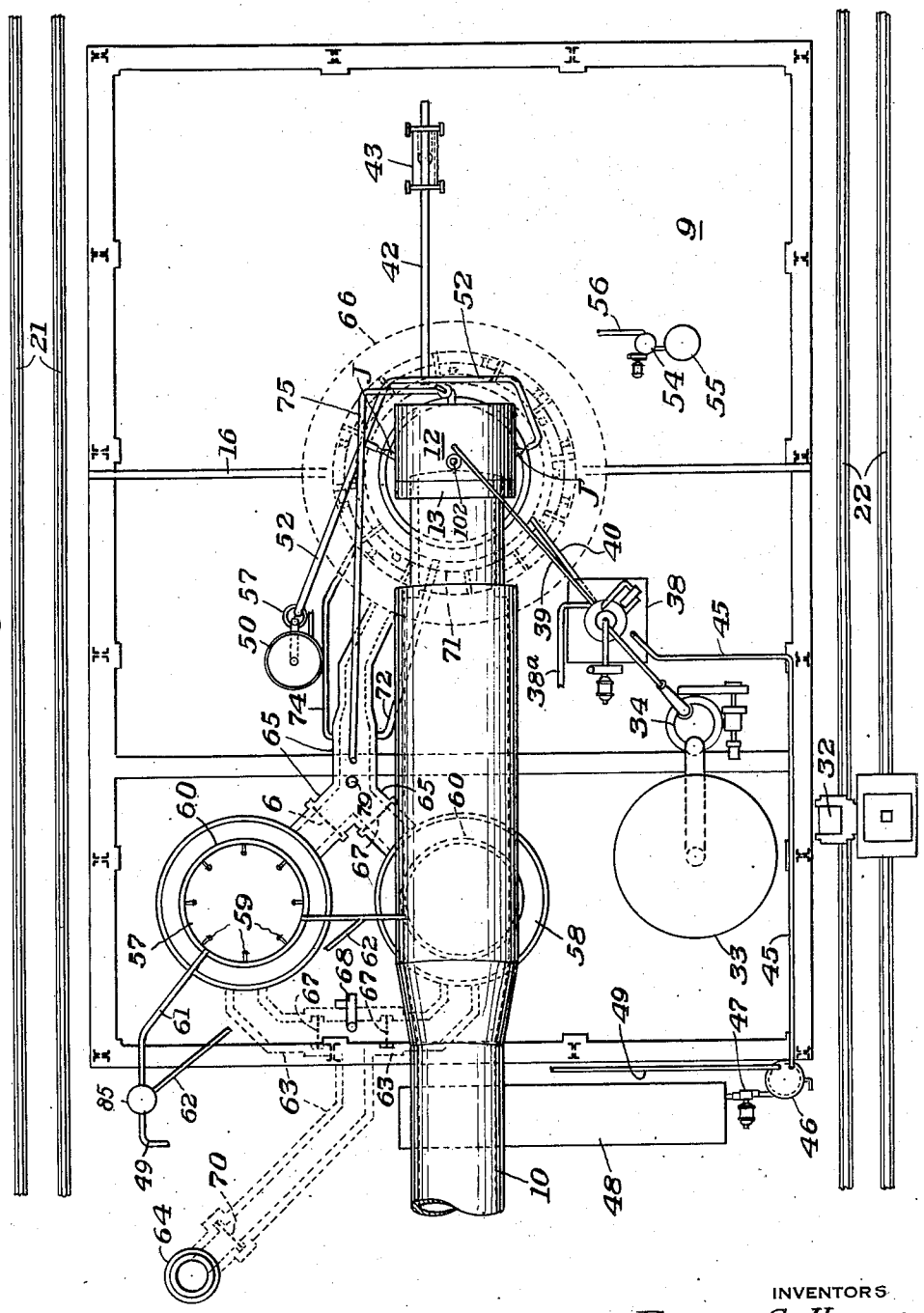
INVENTORS
Eugene S. Harman
Fred H. Loftus
by Christy, Parmelee and Strickland
attorneys

Oct. 24, 1950 E. S. HARMAN ET AL 2,526,658

PROCESS FOR SMELTING IRON ORE

Filed Nov. 25, 1943 7 Sheets-Sheet 6

Fig. VI.



INVENTORS
Eugene S. Harman
Fred H. Loftus
by Christy, Parmelee and Strickland
attorneys

Oct. 24, 1950 E. S. HARMAN ET AL 2,526,658

PROCESS FOR SMELTING IRON ORE

Filed Nov. 25, 1943 7 Sheets-Sheet 7

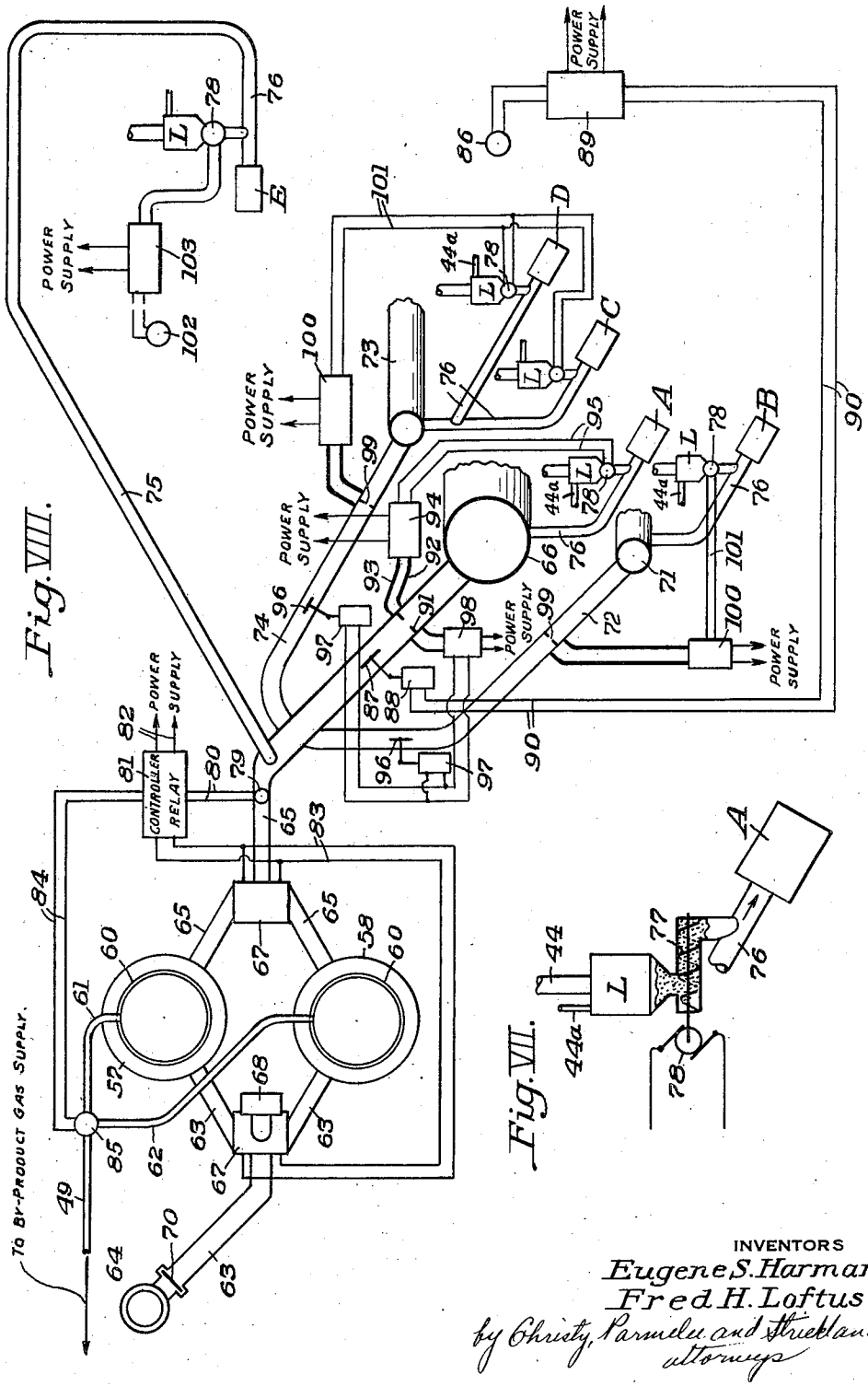


Fig. VIII.

Fig. VII.

INVENTORS
Eugene S. Harman
Fred H. Loftus
by Christy, Parmelee and Strickland
attorneys

Patented Oct. 24, 1950 2,526,658

UNITED STATES PATENT OFFICE

2,526,658

PROCESS FOR SMELTING IRON ORE

Eugene S. Harman and Fred H. Loftus, Mount Lebanon, Pa.; said Loftus assignor to said Harman

Application November 25, 1943, Serial No. 511,672

5 Claims. (Cl. 75—38)

1

Our invention relates to the reduction of iron ore and consists in improvements both in method and in apparatus.

Eugene S. Harman, one of the inventors named herein, filed on March 30, 1942, an application for United States Letters Patent, Serial No. 436,849, now abandoned, disclosing an invention in apparatus for and method of the continuous smelting of iron ore, to provide a relatively pure or refined iron, a metal superior to and more economical than the iron produced in the conventional blast furnace. Our present invention consists in certain new and useful improvements in method and apparatus which are directed to the same end. The improvements herein disclosed lend themselves particularly, though not exclusively, to the teachings of the said Harman application.

The apparatus of the invention includes a rotary kiln and a stationary hearth. In the operation of the apparatus iron ore and ore-reducing materials are advanced through the kiln or shaft zone at a temperature promotive of ore reduction. From the kiln or shaft zone the reduced metal is delivered to the hearth or hearth zone, wherein it is melted at a temperature that is relatively high with respect to the temperature of the kiln. The metal-melting flame in the hearth zone is preferably oxidizing in character in order to obtain the desired high temperature.

The reduction of the ore to iron is effected partly by carbon charged in limited quantity with the ore, and partly by a reducing flame and gases. Carbon in regulated quantity is introduced to the metallic iron in course of its advance from the kiln zone to the hearth zone, this for the purpose of insuring that enough carbon is present to complete the reduction of the ore and to inhibit reoxidation of the metal.

The reducing flame is obtained either by the conversion of the high temperature oxidizing flame streaming from the hearth zone into the reducing zone, and/or by the firing of the hearth zone with a reducing flame whose combustion air has been adequately preheated.

The conversion of the flame from oxidizing to reducing characteristics is preferably effected by the injection of carbon into the flame. Pulverized coke breeze or carbonized coal, preferably preheated to incandescence, is injected into the flaming gases leaving the melting furnace or hearth zone, in such manner as to bring about intimate contact between the coke breeze and the flaming gases, without decreasing the temperature of the flame in the melting furnace. The

2

amount of carbon injected, to convert carbon dioxide into carbon monoxide, is sufficient to establish a $CO:CO_2$ ratio adequate to produce an atmosphere that is at least neutral and preferably reducing. While in electric furnace practice the ratio may be 50:50, in kiln practice a ratio of 65:35 *is* considered to be safely reducing. As already noted, the reaction between carbon and carbon dioxide is endothermic, with the consequence that the injection of carbon lowers the temperature of the gases at the point of injection between the melting furnace and the reducing kiln.

The point of separation of the hearth and shaft zones is located at or near the sintering zone in which the iron turns pasty and becomes nodulized, thus rendering this zone readily accessible to boring bars. The boring bars need not traverse the length of the hearth kiln to reach the pasty iron accumulation on the kiln walls.

As already mentioned, carbon in the form of coke or coal is added to the nodulized iron and slag at the delivery end of the reducing kiln, and the mixture of iron, carbon and slag is progressively discharged into the stationary melting furnace, and caused to form and maintain a pile of material therein. High temperature flames are played upon the sides of the piled material, and the iron and slag are progressively melted and caused to drain to the foot of pile, where a pool of molten iron is formed and maintained, with a blanket of slag floating on top of it. From the melting furnace the flames and hot products of combustion flow into the ore-reducing kiln, and, as above noted, into such flames and products carbon is introduced in quantities adequate to insure that the desired atmosphere shall be established and maintained in the reducing kiln.

The apparatus advantageously includes independently fired hot air stoves, or recuperators, for preheating combustion air. A vertical kiln shaft may also be included as a part of the kiln train, raw materials being charged into the kiln shaft and heated by the hot waste kiln gases of the reducing kiln.

In the accompanying drawings, we illustrate apparatus in which and in the operation of which the invention is realized:

Figure I is a fragmentary view partly in vertical section and partly in side elevation of apparatus embodying the invention;

Figure II is a fragmentary view in plan of the rotary kiln and melting furnace, and the parts immediately associated therewith;

Figure III is a view in vertical section and to larger scale of the melting furnace, on the plane III—III of Figure II;

Figure IV is a central sectional view of the melting furnace, showing partly in section and partly in elevation the equipment organized therewith, the plane of section being at right angles to the plane of Figure III;

Figure V is a view of the apparatus at the melting furnace end, showing the structure partly in side elevation and partly in section on a vertical plane extending on the axis of the kiln;

Figure VI is a fragmentary plan view of the apparatus as seen from above;

Figure VII is a diagrammatic view, partly in section and partly in elevation, of one of the fuel-feeding units for the burners of the melting furnace; and

Figure VIII is a diagrammatic view, illustrating the automatic combustion controls of the apparatus.

Referring to the drawings, the apparatus in general includes a kiln 10, and a melting furnace 11. The kiln is constructed of plate steel, lined with refractory material; the kiln is mounted for rotation in bearing 10*a* (Figures I and II); a ring-gear 10*b* is secured upon the wall of the kiln, and a pinion 10*c*, driven by means of an electric motor 10*d* through a suitable gear-box 10*e*, effects rotation of the kiln at desired velocity. The bearings 10*a* and the mechanism for rotating the kiln may be such as are commonly used for the cement kilns in the art. The kiln 10 is arranged in an inclined position, as indicated in Figure I, and the lower end provides the delivery end of the kiln, while the upper end of the kiln provides the charging end. The lower or delivery end of the kiln extends into a stationary housing 12. A water-cooled ring 13 (Figure III) is carried by the housing 12 in encompassing position upon the end of the rotary kiln, and this water-cooled ring prevents overheating of the kiln body at the delivery end thereof, and provides a relatively close fit between the end of the kiln and the wall of the housing 12, thereby inhibiting infiltration of air into the kiln, and/or undue egress of the gases from within the kiln. The housing 12 is extended through the floor 9 in a passage 14 that opens centrally through the roof of the stationary melting furnace 11 arranged below the floor. The melting furnace is constructed circular in horizonal section, and has a roof of semi-spherical shape. The furnace 11, the uptake or passage 14, and the housing 12 are lined with unburned, chrome-free magnesite brick, the furnace roof being of suspended arch construction. The walls of the uptake 14 may be cooled, after the manner that the bosh walls of a blast furnace are cooled.

Ore, limestone, and carbon (the carbon being in the form of coal, coal coke or oil coke) are dried; crushed to about $\frac{1}{16}$ inch size, and thoroughly mixed, in the proportions of 40:8:5, and then are fed into the kiln 10 at its inlet or charging end. More specifically, bins 1 are provided for the storage of supplies of ore, limestone and coal or coke, and such bins are supplied from railway cars that are unloaded into a hopper 1*a*, whence the materials are conveyed by a skip-bucket 1*b* to the tops of the bins. The furnace-charging materials are removed from the bins, and dried, crushed, weighed and mixed by means of suitable apparatus. The apparatus for this purpose are known in the steel industry,

and it is needless to involve this specification with an illustration and description of them. The mixed materials are delievered by means of a conveyor to a hopper 4 having a chute 5, by way of which chute the mixture is introduced to the rotating kiln 10. The mixed charge may be preheated before introduction to the kiln, and means to this end are fully disclosed in the above-noted pending application Serial No. 436,849. This mixture includes, manifestly, ore-reducing and slag-forming materials.

The mixture thus charged is advanced through the rotating kiln. The kiln is internally heated by means of a hot reducing atmosphere, in the presence of which the ore, through reaction with the solid carbon in the charge, is reduced. As presently will appear, the atmosphere within the kiln consists of the hot waste gases or products of combustion of the melting furnace. The kiln includes a circumferentially enlarged portion 10*f* adjacent to its delivery end, and between this portion 10*f* and the housing 12 the kiln is of reduced diameter relatively to said said portion 10*f*, as indicated at 10*h*. The enlarged kiln portion 10*f* provides a reservoir or holding zone in which the rate of advance of the charge through the kiln is retarded before it enters the portion 10*h* in which, because of the reduced diameter of such portion, the effect of the heat upon the reduced charge is concentrated and the charge sintered.

The metallurgical reactions and calculations that occur as the furnace charge advances through the kiln are considered in minute detail in the pending application above referred to. Suffice it herein to say that the ore in the furnace charge is for the most part reduced in the travel of the charge from the inlet end of the kiln to the kiln zone 10*h* where the material is sintered or nodulized. Upon reaching the delivery end of the kiln, the sintered or nodulized material falls by gravity into the melting furnace.

A boring bar 42 mounted on carriage 43, is provided for dislodging the nodulized and pasty iron which tends to accumulate and stick upon the kiln wall in the sintering zone. In accomplishment of this operation the carriage is moved in right-to-left direction on the floor 9, as indicated in Figure VI, projecting the boring bar through a port (not shown) in the vertical wall of the housing 12, and into position adjacent to the internal wall of the kiln, whereby as the kiln rotates the bar dislodges the accumulated material.

In accordance with our invention, the nodulized iron N (Figure III) and the slag clinker included therewith are caused to cascade from the delivery end of the kiln, and, falling through the passage 14, to form a substantially conical exposed pile P upon the hearth of melting furnace 11, as shown in Fig. III, the pile being maintained at such height as to prevent flotation, and to afford an extended pile surface upon which the melting flames are played. The desired pile height is maintained by controlling the rate of material flow from the kiln, and by regulating the amount of fuel fired for melting the material. The melting flames are played at high temperature upon the surface of the pile, with the effect that the pasty or semi-solid iron and slag clinker are progressively and continuously melted. The melted materials drain to the foot of the pile, forming upon the furnace hearth a bath M of molten metal having an overlying blanket S of

slag. Advantageously, the melting flames are generated by the combustion of fuel with a slight excess of oxygen, in order that the requisite high melting temperature shall be developed.

A reservoir of about eighteen inches of molten metal is normally maintained in the bottom of the furnace, this metal acting as a mother liquor to promote the refinement of the newly melted metal. A tap-hole or iron-notch 15 (Figure IV) is located at the level of the top of the metal reservoir, and when, from time to time, the furnace is tapped, the molten metal flows through a trough 16 into a hot-metal ladle 17.

The blanket S of slag upon the bath M of molten metal operates in known way in the protection and refinement of the metal under the applied heat. To the end that the insulating effect of the slag blanket may be controlled, quantities of slag are flushed off, either intermittently or continuously, through one or more slag-holes 18 opening through the furnace side wall. The tapped slag is delivered by way of a trough 19 into a slag-ladle 20. The ladles 17 and 20 are mounted on railway trucks adapted to travel to desired points within the steel plant on rails 21 and 22.

The melting furnace is fired by means of twelve burners A that are equally spaced circumferentially of, and just above, the periphery of the furnace roof dome. It will be noted in Fig. III that the burners are spaced at points located a substantially interval from the side of the pile P, and are distributed circumferentially thereof. The burners A fire about 90% of the fuel, and the flames of the burners are slightly oxidizing, eight-ninths of the carbon in the fuel burning to CO_2 and one-ninth burning to CO. Above the burners A is provided a row of burners C which inject incandescent pulverized carbon (coke) into the flames and products of combustion for the purpose of converting the CO_2 therein to CO. Additionally, a row of burners D in the wall of the uptake passage 14 is provided for the same purpose. The burners D are staggered with respect to the burners C, in order to give carbon depth or the effect of a carbon bed that insures complete impregnation of the gases flowing from the furnace into the kiln. And through the end wall of housing 12 a burner E opens, this burner operating with a reducing flame at a relatively high temperature.

Through ports J in the opposite side walls of housing 12, carbon in the form of pulverized coal is added to the nodulized material in the sintering zone 10*h* of the kiln, but it may be noted that, even with such introduction of carbon, a small amount of iron oxide (FeO) will be carried with the sinter into the melting furnace. This iron oxide, plus that produced in the melting furnace by reoxidation of reduced metal is present in the blanket S of slag. To facilitate the recovery of this iron oxide contained in the blanket of slag, and to screen the slag-covered bath of metal from the effect of the oxidizing flames of burners A, a layer of CO flames and products of combustion is maintained on top of the bath, such layer of reducing flames and products being provided by firing (with a deficiency of combustion air) through a row of burners B in the side wall of the furnace. Since both the slag and the metal are hot, and both contain carbon, the iron oxide is reduced to iron, the reducing reaction being augmented by the basic chemical properties of the slag (the slag containing a calcium oxide content of 40% or more), and by the effect of the overlying layer of reducing gases.

While substantial quantities of the carbon in the iron are derived from the carbon in the sinter, the actual control of the carbon content or of the refinement of the metal is effected by means of carbon additions made directly into the bath M. Means for this purpose comprise nine refractory tubes 23 that extend through pockets formed at peripherally spaced-apart points in the side wall of the furnace. Pulverized coal, or coke, or charcoal is injected through the tubes into the body of the molten metal M. The carbon thus added comprises coal that is exceptionally low in sulphur, and as presently will appear the apparatus for supplying this so-called metallurgical carbon will be distinct from the apparatus that prepares and supplies the fuel carbon.

In some cases, and as herein illustrated, the metal in the bath M is subjected to the effect of electrodes 24. The electrodes are three in number in this case, spaced 120° apart in the circumference of the furnace; the electrodes extend through pockets in the side wall of the furnace, one of the three electrodes appearing in Figure IV. The means for energizing the electrodes are not illustrated in the drawings, but it will be understood that the well-known practice of the electric furnace art may be followed in this particular. The energized electrodes serve to prevent the metal bath from chilling to a point below that required for the reactions between the slag and the metal. Primarily these electrodes act as temperature boosters, and the current consumed in energizing them is relatively low, it being understood that the electrodes will be operated only as needed to maintain the desired conditions within the body of the bath of metal.

It will be understood that in certain installations the slag will, either with or without the additions of limestone, prove to be of proper composition to provide a cement clinker, which may be ground or pulverized into commercial Portland cement.

Before proceeding with a more detailed description of the combustion equipment of the apparatus, we may explain that the hot reducing gases that flow from the melting furnace through the kiln are discharged into a hood 25. The hood 25 houses the otherwise open charging end of the kiln, and through this hood the charge-introducing chute 5 extends; see Figures I and II. The hood 25 is designed to serve as a gas cleaner; the flue dust separated from the gas is collected in a hopper 26 at the bottom of the hood, whence it is removed at suitable intervals; and the cleansed gas is led off through a duct 27 to a suitable point of disposal. Here we show a boiler installation 28 within a boiler-house 29, and the cleanser gas is used as fuel in firing the boilers, to provide steam for the generation of power. The waste products of combustion of the boiler are drafted to a stack 30. A power-driven fan 31 is provided to propel the fuel gas from the gas cleaner to the boilers, and a dampered by-pass 31*a* (Figure II) leads from the fan outlet to the stack for any bleed-off or recirculation of gas that may be desired.

Turning to a detailed consideration of the combustion system:

Fuel preparing equipment

The coal for fuel is transported in railroad cars over track 22 to a skip-hoist 32, by means of which the coal unloaded from the car is delivered

to a storage hopper 33. In preparing the coal for firing the furnace, the coal is delivered from hopper 33 to a pulverizing machine 34, the delivery being effected by gravity through a duct 35. A blower 36 is organized with the pulverizer, and the pulverized coal is blown from the pulverizer through a pipe 37 to a carbonizer 38 of the type which is fully illustrated and described in United States Letters Patent Nos. 1,954,350; 1,954,351 and 1,954,352. The carbonizer 38 serves, as the name indicates, to carbonize the particles of powdered coal delivered thereto, and also serves to preheat the particles to incandescence in cyclone and recuperator elements included in the carbonizer structure. The operation of the carbonizer unit briefly consists in injecting hot carbonaceous gases and air into the cyclone. Such hot gases are obtained from the kiln housing and waste gas flue, whence by way of pipes 39 and 39*a* respectively, they are fed with a small quantity of air into the cyclone. The mixture of gas and air is introduced by a duct 39*b* tangentially to the cyclone, to give a whirling motion to the gases, and the pulverized coal is injected through the top of the cyclone. The particles of coal are heated in suspension to about 650° F.

The unit 38 includes a blower 38*a* that is effective to recirculate the coal in such manner that the degree of exposure of the coal particles to the hot gases may be regulated. The coal particles are then passed through recuperator plates, whereby they are heated to about 1200° F., and the volatiles distilled off. Since the surfaces of the coal particles are oxidized, adhesion or coking of the particles does not occur. The recuperator is heated by waste gases circulated through the plates, and the distilled volatiles from the unit comprise a by-product coke gas including the usual recoverable substances of a by-product coke plant. As said above, the unit 38 is fully described in the above-noted patents, wherefore further consideration in this specification is not required. Suffice it herein to say that the effect of the unit is to carbonize the coal particles and to preheat them to incandescence, whereby maximum flame temperature may be obtained in the furnace fired with such fuel, and so far as possible water vapor eliminated from the combustion gases.

The incandescent carbon particles are blown by a fan 38*b* from the unit 38 through a pipe 40 into a fuel bustle-pipe or header 41 that encircles the uptake passage 14, the fan 38*b* using exit gas from the cyclone of unit 38 as the conveying medium. From the bustle-pipe or header, fuel lines 44 lead severally to fuel reservoirs L that are severally organized with the burners A, B, C, D and E. The gas used as the conveying medium is piped back from the reservoirs L to the suction side of the fan 38*b* of the carbonizing or coking unit 38, the pipes for this purpose being fragmentarily indicated at 44*a*, Figure VII and VIII.

By-products from fuel

The coke gas from the carbonizing or coking unit 38 is delivered by a pipe 45 to a gas washer and tar precipitator 46. The recovered tar is fed by a pump 47 to a storage tank 48, while the cleansed gas is delivered to a pipe 49, whence it is fed to the regenerators, presently to be described.

Equipment for making carbon additions

The means for making carbon additions to the nodulized sinter N at the delivery end of the kiln comprises a storage bin 50 (Figures IV and VI) from which coal is delivered to a pulverizer unit 51. Pulverized coal is pneumatically conveyed from the pulverizer unit, through a pipe 52, to the nozzles J in the opposite side walls of housing 12. Each nozzle delivers the carbon to the sinter as indicated by the arrow 53 in Figure III.

Still another pulverizer unit 54 is provided. This latter unit is arranged to supply the carbon, in the form of powdered coal in this case, to the molten metal in the furnace 11. As appears in Figures II and VI, the pulverizer unit 54 is supplied with coal from a hopper or bin 55, and a pipe 56, fragmentarily indicated, will be understood to be connected to the refractory tubes 23, through which the pulverized coal is introduced to the bath of molten metal.

By virtue of providing three individual pulverizer units 34, 51 and 54, the chemical and physical qualities of the coal or coke used for the three different purposes may be selected and controlled to best advantage. For example, the pulverized coal introduced to the sinter N is coarsely ground, whilt that added to the molten metal M is advantageously ground to a fine powder. Furthermore, the coal to be coked for the fuel is pulverized to the size most suitable.

Combustion air preheating equipment

The air for the combustion of the fuel is preheated by means of two regenerators or stoves 57 and 58. Each regenerator is fired at the top by means of burners 59 on a manifold 60 (Figure VI). The fuel for the regenerator burners comprises the cleansed by-product gas of the coking unit 38, delivered from the gas washer 46 to the manifolds 60 by piping 61, 62 and 49. The products of combustion are drawn off from the bottoms of the regenerators through a flue system 63 that communicates through a draft-controlling damper 70 to a stack 64, while the air heated in the regenerator is delivered from the tops of the regenerators through a duct system 65 leading to a bustle pipe 66 that supplies the combustion air for the burners A. The flue and duct systems 63 and 65, respectively, are provided with the conventional complement of reversing valves 67, whereby, while one regenerator is being operated to deliver under the propulsion of a fan 68 preheated air for combustion in the furnace 11, the other regenerator is being fired to heat its checkers. From time to time the positions of the valves 67 are reversed, and the regenerator which had been serving to preheat the combustion air becomes the fired regenerator, and the regenerator which had been fired becomes the combustion-air-heating regenerator.

The air for combustion for the burners B is drawn from a bustle pipe 71 connected to the air-supply duct system 65 by a branch pipe 72, and the air for the burners C and D is drawn from a bustle pipe 73 connected to the air-supply duct system by a branch pipe 74. The air for the burner E in the end wall of housing 12 is supplied by an individual pipe 75 leading from said air-supply duct system.

Each of the burners or injectors is connected to the bustle pipe that supplies its combustion and/or injection air means of a branch pipe 76.

By means of automatic temperature control equipment described below, a temperature range of 1800° F. to 2000° F. is maintained, whereby, with constant air flow, the air for combustion may be held at a substantially "straight-line" preheat temperature at or above 1800° F.

Burner equipment

The burners A and B consist of large powdered coal burners. There are twelve burners A spaced circumferentially of the furnace, and these burners burn 90% of the furnace fuel. The burners B are also twelve in number, and these burners burn the remaining 10% of the furnace fuel, the incandescent carbon introduced by burners or nozzles C and D not being termed fuel in the strict sense of the word. The burners B supply the layer of 100% CO flame and gas over the slag covered bath, while the burners A burn the fuel so that 11.11% is burned to CO and 88.89% to CO_2. The average $CO:CO_2$ ratio in the gases of the two sets of burners is 20:80, this ratio being maintained by automatic control equipment, hereinafter described.

There are twelve burners or injectors in each of the two sets C and D for introducing carbon into the combustion gases leaving the furnace. These incandescent coke injectors or burners insure adequate carbon impregnation of the combustion gases flowing from the melting furnace to the reducing kiln, to reform all CO_2 into CO.

The heat content of the gases from the melting furnace is insufficient to supply all of the heat required in the kiln. To compensate for this deficiency the burner E is installed in the housing **12**. This burner operates with a high CO flame. To simplify the control of the kiln atmosphere, the burner E is so adjusted that the analysis of its combustion gases is the same as that of the furnace gases after they have been reformed by the addition of carbon.

With each of the burners or injectors A, B, C, D and E means are provided for delivering powdered fuel from the associate reservoir L into the stream of preheated air jetted through the branch pipe **76** and the burner into the furnace. As shown in Figure VII, such means comprise a screw **77** driven by an electric motor **78** to feed incandescent powdered coke from the reservoir L into the air streaming through pipe **76** into and through the burner A, the burner A in Figure VII being illustrative of each of the burners or injectors provided for heating the furnace and kiln, as well as those for converting the flames and hot products of combustion from oxidizing to adequate reducing characteristics.

Combustion control equipment

In the combustion air duct leading from the regenerators **57** and **58** to the air bustle pipes of the melting furnace is arranged a radiation pyrometer **79**, a known instrument that includes a thermo-couple or pile from which electrical impulses or currents flow, the magnitude of the impulses or current being proportional to the temperature or heat radiation to which the instrument is exposed. As shown diagrammatically in Figure VIII, the radiation pyrometer **79** is connected by lead wires **80** to the conventional controller-relay unit **81**, which operates to open and close electrical contacts between power supply lines **82** and a circuit **83** leading to the electrical valve-reversing mechanisms of the regenerator system (the mechanisms being diagrammatically indicated at **67**, **67** in Figure VIII), and a circuit **84** leading to an electrically operated valve **85** in the fuel supply line to the regenerators. This organization is similar to the known automatic reversal equipment of modern open hearth furnaces, and need not be dwelt upon herein. Suffice it to say that when the temperature of the air delivered by the one regenerator (say regenerator **57**) drops to predetermined value, in this case to 1800° F., the radiation pyrometer **79** is effective through the organization described to shift the reversing valves and the fuel valve **85**, whereby the regenerator **57** which had been serving as the air-heating unit is cut off from the air fan **68** and from the ducts that deliver the heated air to the melting furnace. Also communication between the duct at the bottom of this regenerator and the stack **64** is opened, and a flow of fuel to its burner manifold **60** is established. Simultaneously, the operation of the reversing valves effects the connection of the companion regenerator **58** to the air fan and to the air delivering ducts, and also interrupts the supply of fuel to its burner manifold **60**. Thus, the latter regenerator, **58**, with its highly heated checkers is caused to deliver air to the combustion air bustle pipes of the melting furnace. As in the operation of the furnace the checkers of the air-heating regenerator cool to the point at which the temperature of the delivered air drops to 1800° F., the radiation pyrometer **79** operates again to operate the reversing valves and change over the regenerators. And so the regenerator system operates automatically to afford a continuous supply of highly preheated air to the melting furnace.

The rate of combustion within the melting furnace is automatically regulated to maintain a temperature of desired value—about 3000° F. in this case, and such regulation is effected by means of a radiation pyrometer **86** set in the roof of the furnace. The radiation pyrometer control means adjust the flow of combustion air to the burners A in accordance with variations in furnace temperature, while means function to regulate the delivery of fuel from the reservoirs L to the burners A in accordance with variations in the controlled rate of air delivery. The rate of air delivery to the burners B and injectors or burners C and D is automatically coordinated with the variations in the rate of air flow to the burners A, and as the air flow to burners B, C and D varies the powdered coke delivered thereto is varied.

The means for regulating the flow of air to the bustle pipe **66** that supplies the burners A comprise a butterfly valve **87** in the hot air duct, and a M. E. C. motor drive unit **88** connected to the operating arm of the valve. The unit **88** and other elements of the control organization here described may be purchased on the open market; for example, from Leeds and Northrup Company of Philadelphia, Pennsylvania.

The radiation pyrometer **86** is connected through a controller-relay **89** and a circuit **90** to the electric valve-operating unit **88**, with the effect that, when the furnace temperature to which the radiation pyrometer is exposed tends to rise or fall, the butterfly valve **87** is correspondingly moved towards closed or open position, thus regulating the flow of combustion air to the burners A. The injection of fuel to the burners is regulated in exact proportion to the variations in the flow of combustion air, wherefore it will be understood that the radiation pyrometer system is adapted to regulate the combustion within the furnace to a predetermined temperature that melts the sinter in pile P within the furnace at desired rate.

The instrumentalities that thus regulate the injection of fuel comprise an orifice plate **91** in the air duct, and from the opposite sides of this orifice-plate tubes **92** and **93** extend to a regulator

94. The regulator may be of the well-known type supplied either by Hagan Corporation of Pittsburgh, Pennsylvania, or by Askania Regulator Company of Chicago, Illinois. As the flow of air to the burners A is by the operation of the butterfly valve 87 increased, the pressure drop between the opposite sides of the orifice plate 91 is increased; this variation in differential pressure is transmitted by tubes 92 and 93 to the regulator 94, and in response thereto the regulator operates in known way to vary the energizing current flowing through circuits 95 to the electric motors 78 of each of the fuel-feeding devices 77 of the burners A, whereby the speed of the motors is regulated in accordance with the variations in the combustion air delivered to the burners, and the rate of delivery of the powdered fuel to the burners is correspondingly varied. The rate of combustion maintained by the burners A in the melting furnace is thus regulated automatically, and the temperature within the furnace held to predetermined value.

The flow of air to the bustle pipes 71 and 73 is varied in exact ratio as the flow of air to the bustle pipe 66 is varied. That is to say, a butterfly valve 96 is arranged in each of the branch air ducts 72 and 74; a motor drive unit 97 (similar to unit 88) is connected to each valve 96, and a regulator 98, connected by air lines to the main air duct as the regulator 94 is connected, energizes both units 97 to adjust the valves 96 in the branch air ducts 72 and 74 in correspondence to the adjustment of the valve 87 in the said main air duct. An orifice plate 99 and a regulator 100 are organized with each branch air duct, and by such means the current flowing in the energizing circuits 101 of the fuel-feed motors 78 of each of the burners or ejectors B, C and D is modified in accordance with the variations in air delivered thereto. Thus, the firing rate of the reducing-flame burners B is increased and decreased as the rate of combustion of the metal-melting burners A is increased and decreased. And similarly the rate of injection of the incandescent coke by the burners C and D is automatically regulated in accordance with the variations in the firing rates of the burners A and B, so that the desired $CO:CO_2$ ratio in the products of combustion leaving the melting furnace is automatically maintained.

In addition, the melting furnace and kiln may be provided with the conventional automatic draft control.

When the rate of firing within the melting furnace is automatically reduced, the temperature of the gases passing from the furnace into the kiln drops. In order to compensate for such drop in temperature, the rate of firing of the burner E is automatically increased through the instrumentality of a radiation pyrometer 102, that is located in the roof of housing 12, and arranged, in conjunction with a regulator 103, to control the speed of the fuel-feed motor 78 of the burner. The gases entering the kiln are therefore held at optimum ore-reducing temperature and quality, regardless of variations in the rate of firing in the melting furnace, and thus all of the high temperature heat required for melting and refining the metal in the melting furnace is supplied without in any way interfering with the provision of the atmosphere required in the kiln for the reduction of the ore in the charge—a feature not heretofore available in direct reduction processes.

By virtue of the facts that our process charges a relatively high quantity of limestone, and employs pulverized coke that is lower in sulphur content and less in amount than that charged in the normal blast furnace, there is only a trace of sulphur in the product.

The silica in the ore is not reduced because of absence of excess carbon in the charge. The silica combines with the calcium in the limestone to form compounds of calcium silicates. The carbon in the product is accurately controlled to a content ranging from 0.40% to 1.50%, while the silicon ranges from 0.10% to 0.20%. The phosphorus and manganese reduce with the iron, and in the product there is slightly less of these elements than is present in the ore. Needless to say, a metal of this composition provides an excellent substitute for scrap, much preferable to Bessemer synthetic scrap and to heavy melting scrap. The metal of our process requires no treatment in a Bessemer converter, and in either solid or molten state the metal provides a superior charging stock for open hearth and electric furnaces, for direct refinement into high grades of both alloy and carbon steels. Furthermore, because of its high purity, the required time for refining in either open hearth or electric furnaces is so far reduced that the production of such furnaces may be more than doubled.

It will be understood that within the term and intent of the appended claims, many modifications and variations in structural organization and in method are permissible, and that the reference to "iron ore" in the claims is exemplary for purpose of defining the invention.

We claim as our invention:

1. The method herein described which comprises advancing iron ore, together with slag-forming and ore-reducing materials, through a kiln zone heated to a temperature promotive of ore reduction, nodulizing the reduced ore and slag and delivering them in nodulized condition from said kiln zone into a stationary melting furnace, directing high temperature flames into the melting furnace and converting said nodulized metal and slag to liquid condition and forming on the hearth of said furnace a bath of molten metal having an overlying blanket of slag, leading a stream of flame and hot products of combustion from said furnace into said kiln zone and by the injection of incandescent carbon into said stream establishing a non-oxidizing atmosphere in said kiln zone.

2. The method herein described which comprises reducing iron ore in a reducing zone, delivering the reduced metal into a melting zone, firing the melting zone with high temperature flames, leading the products of combustion from the melting zone into the reducing zone, introducing incandescent carbon into the products of combustion flowing from said melting zone into said reducing zone, and under the effect of variations in melting zone temperature varying the rate of firing.

3. The method herein described which comprises reducing iron ore in a reducing zone, delivering the reduced metal into a melting zone, firing the melting zone with high temperature flames, varying under the effect of variations in melting zone temperature the air and fuel feeding said flames to establish and maintain optimum thermal and chemical atmosphere conditions in said melting zone, leading the products of combustion from the melting zone into the reducing zone, and introducing incandescent carbon into the products of combustion flowing from the melting zone into said reducing zone.

4. The method herein described which comprises reducing iron ore in a reducing zone, delivering the reduced metal into a melting zone, firing the melting zone with high temperature flames, varying under the effect of variations in melting zone temperature the rate of feeding air and fuel to said flames to establish and maintain optimum thermal and chemical atmospheric conditions in said melting zone, leading the products of combustion from the melting zone into the reducing zone, and introducing incandescent carbon into the products of combustion flowing from the melting zone into said reducing zone, and varying the quantity of incandescent carbon introduced to said products of combustion in accordance with variations in said rate of feeding air and fuel.

5. The method herein described which comprises reducing iron ore and nodulizing the reduced ore impregnated with slag-forming and ore-reducing materials in a rotating kiln and dropping the nodules into a furnace chamber containing a pool of molten metal with a blanket of slag floating thereon and forming the nodules into a pile that extends above the surface of said slag-covered pool, directing against the top and side surfaces of the pile exposed above said slag-blanketed pool high temperature flames delivered from points spaced from and distributed circumferentially of said pile, and thereby melting the iron and fluxing said slag-forming materials in the pile and causing the iron to trickle into said pool and the slag-forming materials to enter said slag blanket for protecting the pool of molten metal until it is tapped.

EUGENE S. HARMAN.
FRED H. LOFTUS.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
803,886	Ellis	Nov. 7, 1905
809,291	Fleisher	Jan. 6, 1906
839,126	Ellis	Dec. 25, 1906
911,870	Ellis	Feb. 9, 1909
930,764	Jones	Aug. 10, 1909
983,453	Kjellin	Feb. 7, 1911
1,174,729	Jones	Mar. 7, 1916
1,366,383	Hillhouse	Jan. 25, 1921
1,403,576	Stansfield	Jan. 17, 1922
1,439,957	Garred	Dec. 26, 1922
1,535,174	McGregor	Apr. 28, 1925
1,574,932	Pehrson	Mar. 2, 1926
1,578,280	Gibson	Mar. 30, 1926
1,720,055	Peyrachon	July 9, 1929
1,774,333	Laist	Aug. 26, 1930
1,819,238	Greene	Aug. 18, 1931
1,819,239	Greene	Aug. 18, 1931
1,848,710	Gustafsson	Mar. 8, 1932
1,871,848	Gustafsson	Aug. 16, 1932
1,944,874	Brassert	Jan. 30, 1934
1,954,350	Dornbrook et al.	Apr. 10, 1934
1,954,351	Dornbrook et al.	Apr. 10, 1934
2,035,550	Karwat	Mar. 31, 1936
2,193,845	Stevenson	Mar. 19, 1940
2,195,866	Clarick	Apr. 2, 1940
2,242,219	Baily	May 20, 1941

FOREIGN PATENTS

Number	Country	Date
579,804	France	Oct. 24, 1924