

June 12, 1956

W. E. MARSHALL

2,750,277

PROCESS AND APPARATUS FOR REDUCING AND SMELTING IRON

Filed May 14, 1951

3 Sheets-Sheet 1

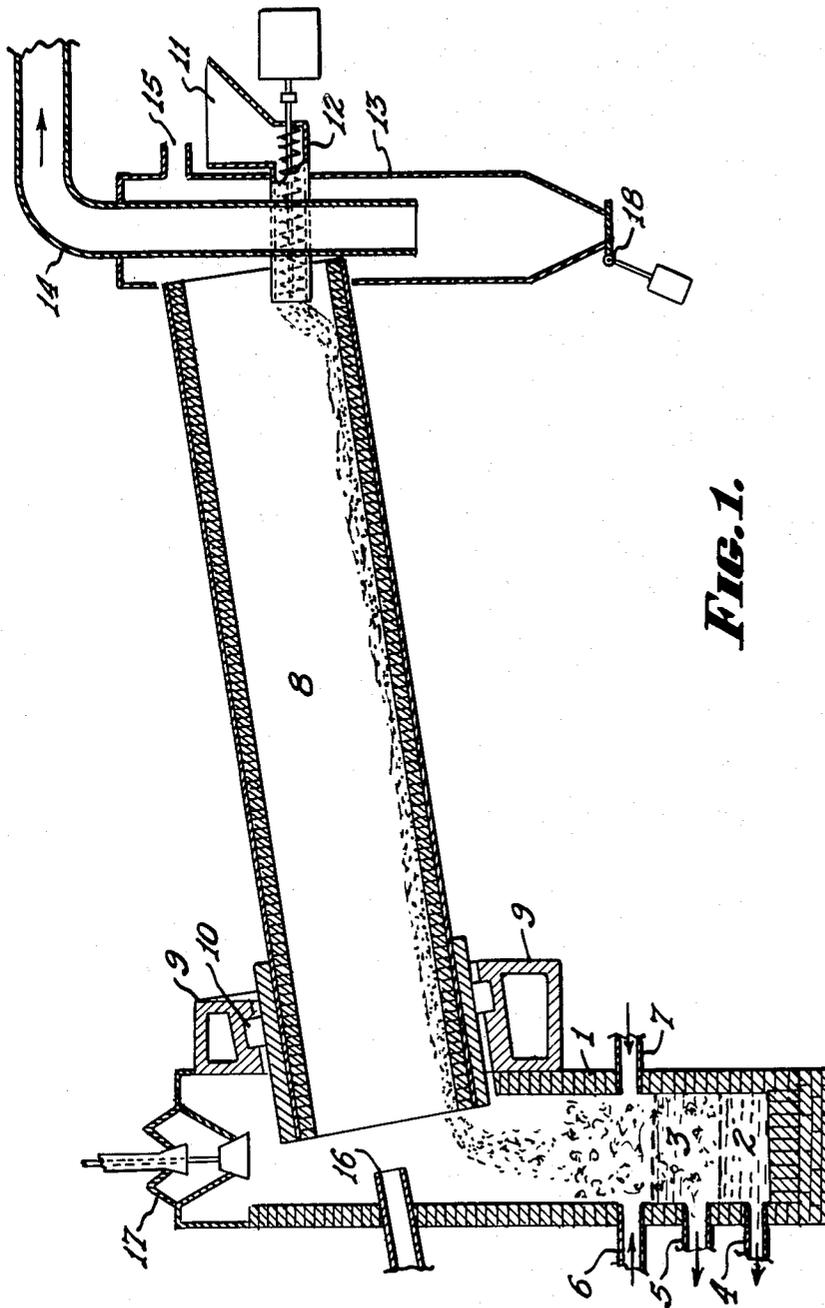


FIG. 1.

INVENTOR.
WILLIAM E. MARSHALL,
BY *Allen & Allen*

ATTORNEYS.

June 12, 1956

W. E. MARSHALL

2,750,277

PROCESS AND APPARATUS FOR REDUCING AND SMELTING IRON

Filed May 14, 1951

3 Sheets-Sheet 2

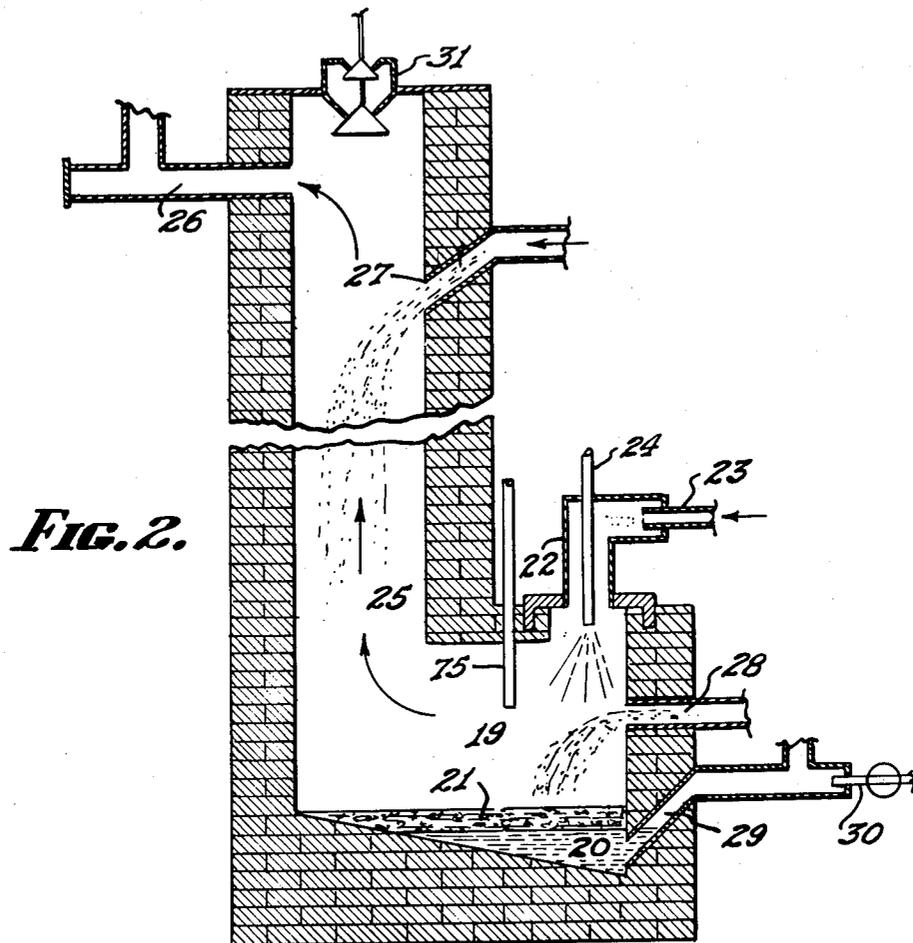


FIG. 2.

INVENTOR.
WILLIAM E. MARSHALL,
BY
Allen & Allen
ATTORNEYS.

June 12, 1956

W. E. MARSHALL

2,750,277

PROCESS AND APPARATUS FOR REDUCING AND SMELTING IRON

Filed May 14, 1951

3 Sheets-Sheet 3

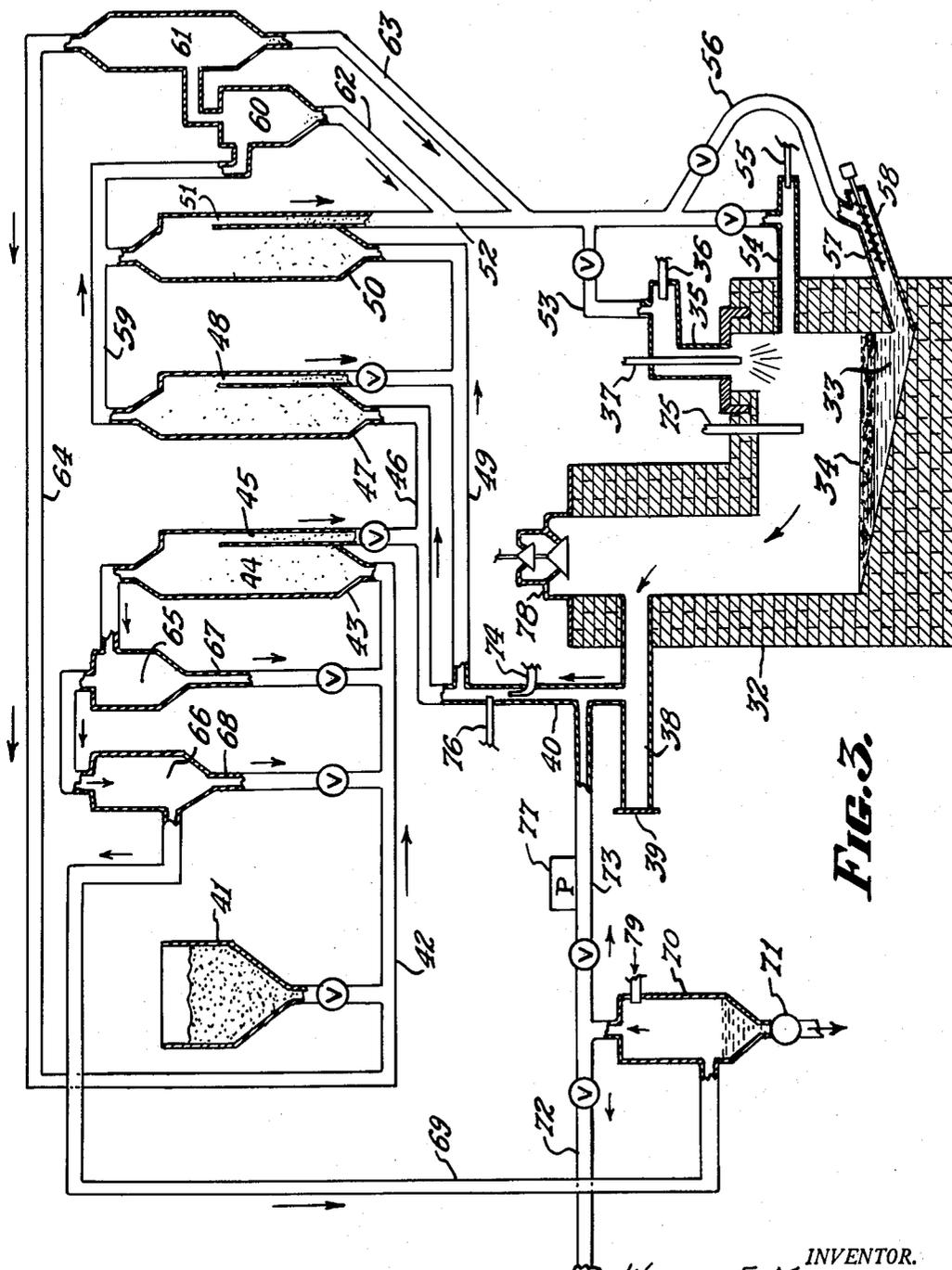


FIG. 3.

INVENTOR.
WILLIAM E. MARSHALL,

BY *Allen & Allen*
ATTORNEYS.

1

2,750,277

PROCESS AND APPARATUS FOR REDUCING AND SMELTING IRON

William E. Marshall, Middletown, Ohio, assignor to Armco Steel Corporation, Middletown, Ohio, a corporation of Ohio

Application May 14, 1951, Serial No. 226,231

13 Claims. (Cl. 75—38)

My invention relates generally to the recovery of iron from ores; and it has for its principal objects:

The provision of a process for the purpose, eliminating the use of the conventional blast furnace and by consequence also eliminating the use of coke as a fuel and as a sustaining skeleton in a shaft furnace;

The provision of a smelting process capable of recovering iron values from finely divided ores, thus eliminating the necessity of briquetting or pelletizing;

The provision of a process and apparatus in which both the required heat and the required reducing atmosphere are derived from the combustion of fuels such as gas, powdered coal or coke, and the like;

The provision of a process in which very substantial economies can be made in the cost per ton of recovered iron; and

The provision of a procedure requiring substantially less capital investment in equipment.

The general objects of the invention and more specific ones which will be set forth hereinafter or will be apparent to one skilled in the art upon reading these specifications, I accomplish by that procedure and in that apparatus of which I shall now describe certain exemplary embodiments. Reference is made to the accompanying drawings in which:

Figure 1 is a schematic sectional view of an apparatus for the direct reduction and smelting of iron ore.

Figure 2 is a diagrammatic sectional view of another form of furnace which I may employ.

Figure 3 is a diagrammatic sectional view of an apparatus in which reduction occurs outside the smelting furnace.

In the conventional blast furnace, as is well known, coke, limestone and iron ore are introduced into the blast furnace shaft through a bell at the top, while air for combustion is introduced lower down in the shaft through tuyeres. The function of the coke is three-fold. It is used to generate heat by combustion with preheated air; and the heat must be sufficient to maintain in the bottom of the shaft a molten pool of iron and slag. The coke also supplies the reducing agent necessary for the reduction of iron from its oxide ores, the reducing agent being in the form of carbon monoxide. But there is yet another indispensable function of the coke. It acts to form a supporting skeleton in the shaft or column of the furnace, which skeleton is porous so as to decrease resistance to the flow of gases upwardly in the shaft. As the percentage of fines in ore has increased in recent years, this third function of the coke has become more important particularly during periods of peak production when every effort is made to blow as much gas through the shaft as is possible.

High production in modern blast furnaces is attained by selecting coke of superior physical properties, discarding the smaller sizes, such as nut and breeze, and by the so-called "layer charging." The cost of operation is steadily increasing because of the difficulty of obtaining coal which will make a strong coke. Some authorities

2

maintain that over the years and per unit of blast furnace capacity, production has decreased about 10% and coke consumption has increased a similar amount.

As is also well known, lump ores of high quality have almost become unavailable; and whether or not it would ever theoretically have been possible to operate a blast furnace on gaseous fuels, it is definitely impossible to do so today without the use of coke because the coke is required to provide voids in the shaft or column of the furnace through which the gases can pass. The relatively fine ores available today mixed with the small amount of limestone required for flux would pack together too tightly in the furnace shaft to permit the necessary passage of gases.

The situation is becoming steadily worse as the highest quality of ore disappears. Available taconites can be concentrated to provide an ore material of sufficient iron content to permit its use; but it is necessary to go further and produce briquettes, sintered masses, nodules or pellets from the fine materials which come from the ore concentrators if these materials are to be used at all in a blast furnace.

It has hitherto been understood that iron ores could be reduced in gaseous atmospheres at relatively low temperatures; but this has not solved the problem of the low cost production of iron because the end product is a spongy mass of reduced iron which requires melting and separation from large quantities of gangue or slag forming materials, and there has been no satisfactorily economical way of melting the iron so formed.

Further, where coke is employed in a blast furnace, it is consumed in various ways. For example, in a heat balance in which 1800 pounds of coke is required for the production of a ton of iron, 1475 pounds burns at the tuyeres, 125 pounds carburizes the iron and reduces metalloids, while the remaining 200 pounds reacts with carbon dioxide to form carbon monoxide and constitutes a waste often referred to as "solution loss." For every pound of carbon lost in this way, or in the direct reduction reaction, another pound and one-half must burn at the tuyeres to make up for the heat consumed. It is not possible to eliminate the essential wastage of coke in the blast furnace; and the blast furnace inherently produces an iron which is high in carbon.

Briefly stated, in the practice of my process, I produce a flame from a gaseous or liquid fuel or a fuel which can be handled in a similar manner, such as natural or artificial gas, oil or powdered coal, which flame must (a) have a temperature above the melting point of the iron produced, and (b) preferably be reducing in character. I use a portion of the sensible heat at least of this flame to maintain a bath of iron in molten condition. I use the reducing characteristics of the products of combustion of the flame to reduce iron ore to iron in particle form. Finally, I melt the reduced iron into the molten bath.

The procedure can be carried on in various ways and in different types of apparatus; but a shaft furnace such as the blast furnace, in which the gases pass through a load in the shaft, is not employed. The problem of providing porosity as well as structural strength in a load in a shaft furnace is not present in the procedure of this invention. The furnace, instead, takes essentially the form of a bath-type furnace in which a pool of molten iron, covered, of course, with slag, is maintained molten by the heat of a flame above it more or less as in an open hearth furnace. The use of coke for the three purposes which it serves in the blast furnace, namely as a fuel to generate heat, as a means for generating a suitably reducing atmosphere, and as a means for supporting a porous load, is eliminated entirely. The process of this invention does not preclude the addition of coke or other form

of carbon for the purpose of carburizing the iron, where this is desired; and it will be understood that a high carbon iron will melt at a somewhat lower temperature than a lower carbon iron.

The feasibility of the process of this invention is dependent upon the production from the types of fuels here contemplated of a flame which has both the required temperature and the required reducing characteristics. This can be done in two ways: either by preheating the air employed for combustion, or by enriching the oxygen content of the air. Both expedients may be adopted if desired. The preheating of the air to maintain the required flame temperature, which should be at least about 2500° F. and preferably around 3000° F. or above, is feasible and can readily be employed. However, the enrichment of the oxygen content of the air is generally preferred in the practice of my process and will be found more economical as well as more convenient where a supply of oxygen is available cheaply or can be made as an incident to the practice of the process. The required heat in the flame can generally be attained by enriching the air for combustion with oxygen to a content of, say, 30% or greater; and with an oxygen enriched air containing substantially 40% to 50% of oxygen, no preheating of the gas is ordinarily required. There is, of course, no limit on the oxygen which may be used up to and including 100% of the gas introduced along with the fuel into the combustion zone.

The nature of the fuels which may be employed has already been generally outlined. The contents of combustible matters in different fuels will, of course, vary chemically and in percentage. A necessary characteristic of the flame and its products of combustion is that they be reducing in character. This means that the proportion of fuel and oxygen in the combustible mixture must be controlled so as to permit the production of very little carbon dioxide. Hydrocarbon fuels can be completely burned to carbon dioxide and water, but this is to be avoided. The carbon should principally be burned only to carbon monoxide; and the ratio of hydrogen to water vapor in the products of combustion should be kept at least about 1:1 in order to prevent the development of a condition oxidizing to iron. With different fuels, the precise amount of oxygen required to produce the desired reducing atmosphere will vary; but it is possible with any available gaseous, liquid or powdered fuel to limit the quantity of oxygen so as to produce a reducing flame of the character set forth above, while at the same time the temperature of the flame can be controlled by limiting the quantities of inert gas which must be heated by the flame (i. e. enriching the air with oxygen), or by preheating the air, or both. Since in several modifications of the invention a mixture of reduced iron and lime as a flux will be subjected to the direct action of the flame so as to be melted into a bath of molten iron, the flame must act to preserve the reduced character of the iron. As a gaseous mixture enters a furnace and is burned, some portion of the flame may be of oxidizing character; but this in itself is of no consequence providing the remaining portion of the flame is reducing and acts either to preserve the reduced character of the iron or to reduce it before it enters the bath.

Referring to Figure 1, there has been shown a furnace 1 containing in its lower portion a bath 2 of molten iron and a supernatant bath 3 of slag. Tap holes 4 and 5 are provided for both baths. The reducing flame or flames hereinabove characterized are introduced into the furnace through burners or tuyers indicated at 6 and 7. Sufficient heat is generated by the reducing flames to keep the baths of iron and slag molten; and the products of combustion, which are reduced in character, pass from the furnace through a rotary kiln 8 supported adjacent the furnace in a water cooled casting 9, which serves also to support a suitable gas seal 10.

Into the opposite end of the kiln 8 there is introduced a

mixture of finely divided ore and limestone or calcined lime through a hopper 11 from which the finely divided mixture is introduced into the kiln at a suitable rate of feed by means of a power screw 12 or otherwise. The reducing gases from the furnace 1 pass through the kiln 8 and into a housing 13 at its opposite end whence they pass to a stack or conduit 14. A peep sight 15 may be provided in the housing. The action of the reducing gases in the rotary kiln 8 is to reduce the iron ore to metallic iron and to calcine the limestone where this material is employed as a flux. The rotation of the kiln helps to prevent a sintering of the reduced or unreduced materials therein. Where necessary, it is within the scope of the invention to enrich the gases in the kiln 8 with hydrogen or other reducing gases, such as natural gas, introduced through one or more nozzles 16.

The cracking of natural or other hydrocarbon gases used for enrichment will be productive of finely divided carbon. This substance, however, tends to prevent sintering of the ore, may under certain circumstances tend to reduce carbon dioxide, and in any event is a fuel the ultimate values of which are not lost in my system.

By the time the mixture of iron ore and lime reaches the end of the kiln 8 and spills over into the furnace 1, the iron will have been reduced; and it will be melted into the bath 2 by the heat of the flames from burners 6 and 7, the lime, of course, being melted into the slag bath 3. At the top of the furnace, as indicated at 17, a bell may be provided to permit the introduction of control materials into the bath in the furnace. Alloying ingredients can thus be introduced as can coke or other suitable form of carbon for the purpose of adding to the carbon content of the iron in the bath 2. Melting temperatures may be varied somewhat in this manner; but the process is not dependent upon the addition of solid carbon to the iron, and it is an advantage of the process that low carbon irons may be directly produced, requiring less ultimate refining, as in an open hearth.

The housing 13 may be provided with a lower door 18 for the removal of any materials collecting therein. It will further be understood that any combustible values in the gases passing through the conduit or stack 14 may be recovered in any suitable way. The heat values may be employed in part to preheat the enriched air at the tuyeres 6 and 7, or power derived from the heat values may be used for other purposes such, for example, as the local production of oxygen.

Figure 1 is essentially diagrammatic in character, although it sets forth a feasible procedure. There are other ways, however, in which the reducing gases generated by the flames may be employed for the reduction of ore. In Figure 2 there is shown a bath-type furnace 19 containing a body of molten iron 20 and a bath of slag 21. A flame through a burner 22 is caused to impinge upon the surface of the molten baths in the furnace, the burner being provided with a conduit 23 for the fuel and a conduit 24 for oxygen or oxygen enriched air. The products of combustion of the flame pass from the furnace through a vertically elongated stack 25 to a flue 26. There is shown at 27 a means for introducing into the stack 25 either a finely divided mixture of iron ore and flux or partially or wholly reduced powdered iron, as the case may be. The velocity of gas flow through the stack 25 may be controlled by variations in the dimension of the stack so that the finely divided materials will fall through the hot reducing gases and, in the case of iron ore, be reduced thereby and ultimately melted into the bath 20. It is also possible in such a furnace to introduce through an opening 28 a pre-reduced mixture of iron and flux which can be blown into the furnace by the blast of reducing gas, such as a portion of the gas passing through the stack 26 and re-circulated as by means of a pump. The reduced iron and flux mixture may be so introduced into the furnace as to be blown by the flame down into the molten baths on the furnace bottom and the flame

5

blast may be so regulated as to keep some or all of the slag swept aside from the point of impingement. But it is also possible to introduce a pre-reduced mixture of iron and flux into the molten iron bath 20, as through a conduit 29. Here again, the pre-reduced mixture may be blown into the furnace by a blast of reducing or flue gas through a nozzle 30. Means for reducing iron ore outside the confines of the furnace proper will be described in connection with Figure 3. Again, there is shown a bell 31 for the introduction of control elements into the bath where this is desired.

Referring to Figure 3, there is shown a hearth or bath-type furnace 32 which, since the reduction of the iron ore is to occur outside the furnace, need not be provided with an elongated stack. The bath of molten iron is shown at 33, and the molten slag at 34. Again, a burner is provided at 35 with inlets 36 for natural gas, oil, or powdered fuels, and at 37 for oxygen or oxygen enriched air.

The flame impinging upon the surface of the molten baths in the bottom of the furnace produces products of combustion of reducing character which pass to a flue 38 equipped with a safety valve 39 and thence through a conduit 40 to a reducing apparatus which will next be generally described.

A hopper 41 is provided for a mixture of finely divided dry iron ore and flux, such as limestone or calcined lime. The mixture passes into a conduit 42 where it becomes entrained in gas as hereinafter described and may, if desired, be carried to a preheater and reducer indicated at 43. The reducing devices shown in Figure 3 are of a type in which the material to be reduced is carried along by and kept in a state of agitation by a moving body of gas. Similar apparatus has been used in the oil cracking industry and has also been suggested for the reduction of iron ore to powdered iron so that specific novelty is not here claimed therein. The preheating reducer 43 has a body, as shown, in which the ore and flux mixture tends to collect as at 44, while the gas passes through it and keeps it in a state of fluid-like agitation. As the material collects, it spills over into a passageway 45 and is carried downwardly into a conduit 46 in connection with the conduit 40, so that it becomes entrained and is carried along by gas from the flue 38. It passes to another reducing apparatus 47 constructed similarly to the device 44, the reduced or partially reduced material spilling over into the passageway connected with a conduit 49 which is also a branch of the conduit 40; and becoming entrained in the gas in the conduit 49, the reduced or partially reduced material may be carried to yet another reducing device 50 of similar construction.

It will be evident that the mixture of ore and flux will have been treated in the reducing devices 47 and 50 sequentially with the reducing atmosphere derived from the flame in the furnace 32 and that reduction of the iron ore will have occurred therein together with a calcining of the limestone if this material was employed as a flux. The reduced mixture of metal and flux passes from the second reducing chamber 50 through the passageway 51 into a conduit 52 by which it is carried to the furnace for melting into the bath. It may be introduced into the furnace in any of several ways or combinations of ways. For example, the conduit 52 may have a connection 53 with the burner element 35 so that the reduced mixture can be introduced into the furnace with or in the flame. Yet again, it may be introduced into the furnace through a conduit 54 above the molten baths but in such a position that the force of the flame will drive it down into the baths as described above. The propulsion of the reduced mixture may be assisted by a blast of non-oxidizing gas through a nozzle 55. As hereinabove described, the reduced material may be forced into the furnace beneath the surface of the bath 33 of molten iron. A branch conduit 56 has been shown connecting the conduit 52 with a furnace passageway means 57. Here the reduced ma-

6

terial may be blown beneath the surface of the bath by a blast of gas, as described in connection with Figure 2, or it may be pushed beneath the surface, as by a power screw 58. In the various conduits throughout Figure 3, circles cutting across conduits have been used to indicate valves. A plurality of connections may be provided as shown, or a single mode of introduction into the furnace may be adopted for the reduced materials.

As indicated above, the reducing gases from the furnace passing into the reducing chambers 47 and 50 produce a reduction of the iron ore therein. The gases, which may still contain reducing values, are collected in a conduit 59 from both reducing chambers and pass thence through separating means, such as a cyclone separator 60 and an electrostatic precipitator 61 in series. The outlets for separated solids from these devices, which outlets are indicated at 62 and 63, connect with the conduit 52 and merely add to the volume of reduced mixture carried by the last named conduit. The gases from the separating devices are carried by a conduit 64 to the entrance side of the apparatus and are used to entrain the fresh mixture of iron ore and flux from the hopper 41 and carry it through the conduit 42. The preheating reducer 43 described above is not a necessary feature of the apparatus and may be omitted if desired. Where used, however, the gases in conduits 64 and 42 pass through it and thence to a cyclone separator 65 and an electrostatic precipitator 66, the solids outlets of which, 67 and 68, feed into the conduit 42.

The gas from the separators 65 and 66 is carried by a conduit 69 to a cooler or gas washer 70 which serves to remove from the gas water vapor picked up in the reduction of iron so as in part to restore the reducing character of the gases, the cooling water being introduced at 79 and disposed of through the outlet 71. The washed gas passes through a conduit 72 to a place of use. Normally, this gas will contain combustible values which can be used in various ways. As indicated above, the combustible values may be used in preheating oxygen or enriched air introduced into the burner 35, or they may be used under boilers or in turbines employed for the generation of power for any appropriate use, as for example, in the local manufacture of oxygen. A portion of the washed top gases may, however, be re-introduced into the system through a conduit 73 connecting the gas washer with the conduit 40. Where this is done the washed and cooled top gases serve to cool and dilute the flue gases from the furnace 32. This is of importance because while very substantial agitation is maintained in the reducing chambers 43, 47 and 50, the temperature cannot be allowed to rise therein to such a value as to cause sintering or agglomeration of the ore-flux mixture or its reduction products. The reduction of iron ore can occur efficiently at temperatures far lower than the melting point of iron. As will be understood by the skilled worker in the art, the reducing characteristics of the atmosphere will be altered by temperature especially with respect to the effect of the hydrogen-water vapor ratio. The essential characteristic of the atmosphere is that it be maintained reducing toward iron oxide and iron. If the fuel being consumed is one producing fairly large quantities of water vapor under the particular reducing conditions of combustion, it may be satisfactorily reducing at temperatures near 3000° F. while insufficiently reducing if cooled to half that temperature or somewhat above. Under these and similar circumstances, it is within the scope of the invention to increase the hydrogen-water vapor ratio of the gases from the furnace prior to their introduction into the reducing chambers 47 and 50 by feeding into the gases a reducing gas which may be hydrogen or a hydrogen-bearing combustible gas, such as natural gas. A nozzle for the purpose of feeding reducing gas into the conduit 40 has been indicated at 74. For the purpose of temperature measurement, thermo-

couples or other suitable means may be provided in the system at any desired locations. A thermocouple 75 or the like has been shown associated with the furnace 32 and another 76 has been shown in the path of the flue gases from the furnace 32. Circulation of the gases may be effected or made more positive through the use of booster pumps or blowers. One such pump has been indicated at 77, associated with the conduit 73. Other pumps may be employed wherever desired in the system. Again, a bell 78 has been shown associated with the furnace 32 for the introduction of control materials into the furnace, as explained above. In Figure 3 arrows have been employed to indicate the directions of the flow in the several conduits and in the furnace.

The control of combustion in the operation of the furnace is not difficult in the light of the teachings made herein. The temperature can be controlled by manual or automatic regulation of the combustion mixture. With any given fuel, it is possible to work out by formula equations, taking into account the volumes of gases involved for the fuel, the oxygen or enriched air employed, the temperature of preheat, the temperature of the flame, and the reducing characteristics of the products of combustion. Such calculations need not be made for the practice of the process, however, if the factors are variable. The fuels which may be used include (1) natural and artificial combustible gases such as natural gas, methane, ethane, propane, butane, ethylene, acetylene, hydrogen, etc., which contain as their principal combustion components hydrogen or hydrocarbons, but avoiding more than minor concentrations of gases containing combined oxygen, such as carbon monoxide and water vapor, (2) oil or other liquid hydrocarbon fuels, (3) solid pulverized carbonaceous fuels such as powdered coal, coke, or carbon black. With all of these fuels, the quantity of combustible material present with relation to inert or non-combustible material is such that a sufficient hot flame can be attained with incomplete combustion both of carbon and of hydrogen providing the quantity of gas to be heated to flame temperature by the combustion is not too great. A flame, the products of combustion of which are reducing to iron oxide is ordinarily attained when the CO—CO₂ ratio is as great as practicable and not less than about 2 and the H₂—H₂O ratio is one or greater. As indicated, the conditions can be attained with ordinary air for combustion by preheating this air to temperatures of the order of 1500–2000° F., but the conditions can also be met by reducing the volume of inert gas in the atmosphere used for combustion, i. e., by enriching air with oxygen. Thus, as also set forth, no preheating of the atmosphere used for combustion is required if the quantity of oxygen in it is increased to around 40% to 50%. Preheating plus enrichment of the air can be practiced also, in which event the extent of the enrichment can be cut down and the enriched air need not be heated to so high a temperature. But flame temperatures are readily measurable in the furnace, and the reducing nature of the resultant products of combustion can be determined by gas analysis or by the effect of the atmosphere in reducing iron ore under given temperatures. Thus with means for controlling the quantity of atmosphere admitted in relation to the quantity of fuel, the degree of enrichment of the atmosphere with oxygen and, where employed, the degree of preheating of the atmosphere, the skilled combustion engineer can readily attain, in the light of these teachings, a flame of the required temperature and a sufficiently reducing nature in the products of combustion. Any cracking of gases or liquid fuels occurring in the system occurs in the furnace and does not require separate apparatus.

The invention is not limited to the generation of a flame the products of combustion of which will directly and rapidly reduce iron oxide at flame temperatures or lower. It is possible to use a flame which is not of this

character providing (a) the products of combustion are sufficiently enriched with reducing gas prior to their use in reducing the finely divided iron and (b) precautions are taken to melt the reduced iron into the bath without reoxidizing it, as by introducing it into the furnace beneath the surface of the bath as described above, or (c) if some reoxidation is unavoidable enough carbon is added to the bath to re-reduce the oxide.

Where preheating of the atmosphere is not employed, stoves for the purpose are likewise rendered unnecessary. The losses inherent in the use of coke as a fuel, as a source of carbon monoxide and as a supporting skeleton in a shaft furnace, are eliminated entirely, as are the inherent losses in the carbon values of coke. The apparatus required is simpler and less costly both in procurement and upkeep and, depending somewhat upon the quality of the ore, iron is recovered in molten form without excessive slag. Since the furnace is essentially a bath-type furnace, as distinguished from a shaft furnace, it is possible to tap the slag continuously or at frequent intervals so as to make the flame more directly effective in maintaining in molten condition the bath of iron. Lower grade ores may be employed to better effect than in conventional reduction and smelting processes and a finely divided condition of the ore is an advantage for rapidity of reduction. There is no loss of fines from the system of this invention so that no extra cost is involved for sintering or pelletizing ore materials. Depending upon the local costs of fuel and oxygen, very great savings can usually be made in the cost per ton of reducing and smelting iron; and the process makes it possible economically to smelt iron in locations where that could not otherwise be done.

The various fuels mentioned herein are referred to for convenience in the appended claims as "mobile fuels."

Modifications may be made in the invention without departing from the spirit of it. Having thus described the invention in certain exemplary embodiments, what I claim as new and desire to secure by Letters Patent is:

1. A process of reducing and smelting iron ore which comprises producing in a bath-type furnace with a mobile fuel a flame having a temperature of at least substantially 3000° F., the products of combustion of which are reducing to iron oxide, employing heat from said flame to maintain in molten condition a bath of iron in said furnace, employing said reducing products of combustion in heated condition outside said furnace to reduce divided iron ore to iron in particle form, and melting said reduced particle iron into said bath, said flame being caused to impinge on said bath and said reduced particle iron being introduced into said furnace below said flame so as to be blown into said bath thereby.

2. A process of reducing and smelting iron ore in finely divided condition, which comprises producing in a furnace with a mobile fuel a flame having a temperature of at least substantially 3000° F., the products of combustion of which within the said furnace and at substantially the melting point of iron will be sufficiently reducing to iron oxide to prevent re-oxidation of finely divided reduced iron introduced into the said furnace and to effect reduction of incompletely reduced iron oxide if present, removing the said products of combustion from the said furnace, cooling them, increasing their reducing potential, and employing the so treated products of combustion for at least the partial reduction of finely divided iron ore entrained therein, and introducing the so reduced material in finely divided form into the said furnace and into the said flame so that the said products of combustion at high temperature exert a reducing effect on any unreduced portion thereof, and the said flame melts the reduced iron.

3. The process claimed in claim 2, wherein the said finely divided iron ore is admixed with finely divided flux prior to reduction outside the said furnace, and wherein the said flame melts the said flux in the furnace to form a slag.

4. A process of reducing and smelting iron ore which

9

comprises producing in a bath-type furnace with a mobile fuel a flame having a temperature of at least substantially 3000° F., the products of combustion of which are reducing to iron oxide, the said products of combustion having a CO:CO₂ ratio not less than 2:1 and a H₂:H₂O ratio not less than 1:1 at 3000° F., causing heat from said flame to maintain in molten condition a bath of iron in said furnace, causing said products of combustion to reduce divided iron ore to iron in particle form, and melting said reduced particle iron into said bath by means of the heat of said flame, in which process said iron ore is entrained in said products of combustion and treated thereby in a fluo-solid reduction chamber, and thereafter introduced into said furnace for melting, and in which the temperature of said products of combustion is controlled to prevent sintering in said chamber by mixing therewith a portion of cooled gases from said reduction chamber, and enriching said products of combustion with reducing gas prior to causing said products of combustion to enter said reducing chamber.

5. In apparatus for the purpose described, a bath-type furnace for containing a bath of molten iron, burner means for producing a flame in said furnace for maintaining said bath in molten condition, means for controlling the combustion of said flame to produce products of combustion forming an atmosphere reducing to iron oxide, means for bringing said reducing atmosphere into contact with a mixture of divided iron ore and flux outside said furnace so as to reduce said iron ore to iron in particle form, and means for bringing said reduced iron and flux into contact with said bath whereby to melt said iron into said bath, the means for bringing said atmosphere and said mixture of divided ore and flux into contact with each other comprising a fluo-solid reduction chamber outside said furnace having connection therewith for said atmosphere, means for entraining said mixture in said atmosphere and a connection with said furnace for delivering said mixture after reduction thereto, said burner being directed to cause said flame to impinge on said bath and said last mentioned connection having an outlet located to deliver said mixture after reduction into said furnace below said flame whereby said mixture is blown into said bath by said flame.

6. In apparatus for the purpose described, a bath-type furnace for containing a bath of molten iron, burner means for producing a flame in said furnace for maintaining said bath in molten condition, means for controlling the combustion of said flame to produce products of combustion forming an atmosphere reducing to iron oxide, means for bringing said reducing atmosphere into contact with a mixture of divided iron ore and flux outside said furnace so as to reduce said iron ore to iron in particle form, and means for bringing said reduced iron and flux into contact with said bath, whereby to melt said iron into said bath, said means for bringing said atmosphere and said mixture of divided ore and flux into contact with each other comprising a fluo-solid reduction chamber outside said furnace having connection therewith for said atmosphere, means for entraining said mixture in said atmosphere and a connection with said furnace for delivering the said mixture after reduction thereto, said last mentioned connection opening into said furnace below the sur-

10

face of said bath so as to introduce said mixture after reduction directly into said bath.

7. A process of reducing and smelting iron ore for the production of liquid metal which comprises producing in a furnace melting chamber and with a mobile fuel a free flame having a temperature of at least substantially 3000° F., the products of combustion of which are reducing to iron oxide, causing said reducing products of combustion to reduce finely divided iron ore outside said melting chamber, and introducing the so treated material in particle form into said melting chamber through said flame so as to be melted therein by the heat thereof.

8. The process claimed in claim 7, wherein the said reducing products of combustion are withdrawn from said melting chamber, reinforced as to their reducing value and cooled to lower than flame temperature, so that the reducing treatment of said finely divided iron ore is carried on without sintering.

9. The process claimed in claim 8, wherein the said reduction outside the melting chamber is carried on under fluo-solid conditions.

10. The process claimed in claim 7, wherein the said reduction outside the melting chamber is carried on under fluo-solid conditions, in which the said flame is formed in said melting chamber by means of a burner, and in which the treated finely divided material is introduced into the melting chamber through the said burner.

11. Apparatus for the purpose described, comprising a furnace having a melting chamber, burner means for producing in said chamber a free flame from a mobile fuel having a temperature of at least about 3000° F., the products of combustion of which are reducing to iron oxide, reducing means outside said melting chamber having a connection therewith for the said reducing products of combustion, means for introducing into said reducing means finely divided iron ore to be subjected to a reducing treatment by said products of combustion, and means for introducing into the said melting chamber through said flame the so treated materials in particle form.

12. Apparatus as claimed in claim 11, including means intermediate said melting chamber and said reducing means for reinforcing the reducing potential of said products of combustion and cooling them to below flame temperature, whereby sintering of the particle-form material is avoided.

13. Apparatus as claimed in claim 12, in which the reducing means is a fluo-solid reducing apparatus.

References Cited in the file of this patent

UNITED STATES PATENTS

722,253	Ruthenburg	Mar. 10, 1903
1,948,697	Brassert	Feb. 27, 1934
2,035,550	Karwat	Mar. 31, 1936
2,039,087	Kinzel	Apr. 28, 1936
2,066,665	Baily	Jan. 5, 1937
2,300,141	Whitzel	Oct. 27, 1942
2,493,391	Chew	Jan. 3, 1950
2,538,201	Kalbach et al.	Jan. 16, 1951

FOREIGN PATENTS

580,142	Germany	July 6, 1933
---------	---------	--------------