United States Patent [19]

Von Waclawiczek et al.

[11] **3,862,834**

[45] **Jan. 28, 1975**

[54] **METHOD FOR PRODUCING STEEL**

[75] Inventors: **Herbert Ritter Von Waclawiczek,** Duisburg; **Klaus Ermisch,** Essen, both of Germany

[73] Assignee: **Fried Krupp Gesellschaft mit beschrankter Haftung,** Essen, Germany

[22] Filed: **Aug. 1, 1972**

[21] Appl. No.: **277,034**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 240,641, April 3, 1972, abandoned.

[30] **Foreign Application Priority Data**

Apr. 3, 1971 Germany 2116445

[52] **U.S. Cl.** ..... **75/11,** 75/0.5 B, 75/12

[51] **Int. Cl.** **C22d 7/00**

[58] **Field of Search** ..... 75/0.5 B, 10–12

[56] **References Cited**

UNITED STATES PATENTS

3,290,723	12/1966	Jaques	75/0.5 B
3,342,250	9/1967	Treppschuh	75/10 R
3,347,766	10/1967	Death	75/10 R
3,429,691	2/1969	McLaughlin	75/10 R
3,475,158	10/1969	Neuenschwander	75/10 R
3,547,622	12/1970	Hutchinson	75/10 R
3,615,349	10/1971	Bleloch	75/11

Primary Examiner—L. Dewayne Rutledge
Assistant Examiner—Peter D. Rosenberg
Attorney, Agent, or Firm—Spencer & Kaye

[57] **ABSTRACT**

A method for reducing iron ore dust, including forming the dust into a cloud, transporting the cloud in reducing gas, reacting the cloud with the gas for enriching the dust, and introducing the transported cloud into the plasma stream of a plasma burner whose plasma stream is penetrating into the bath of a melting furnace.

9 Claims, 10 Drawing Figures

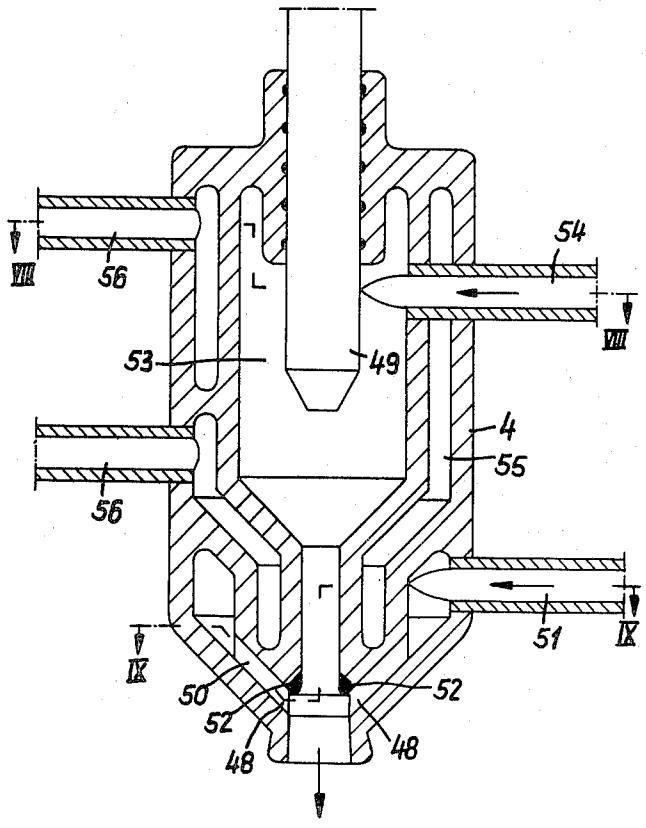
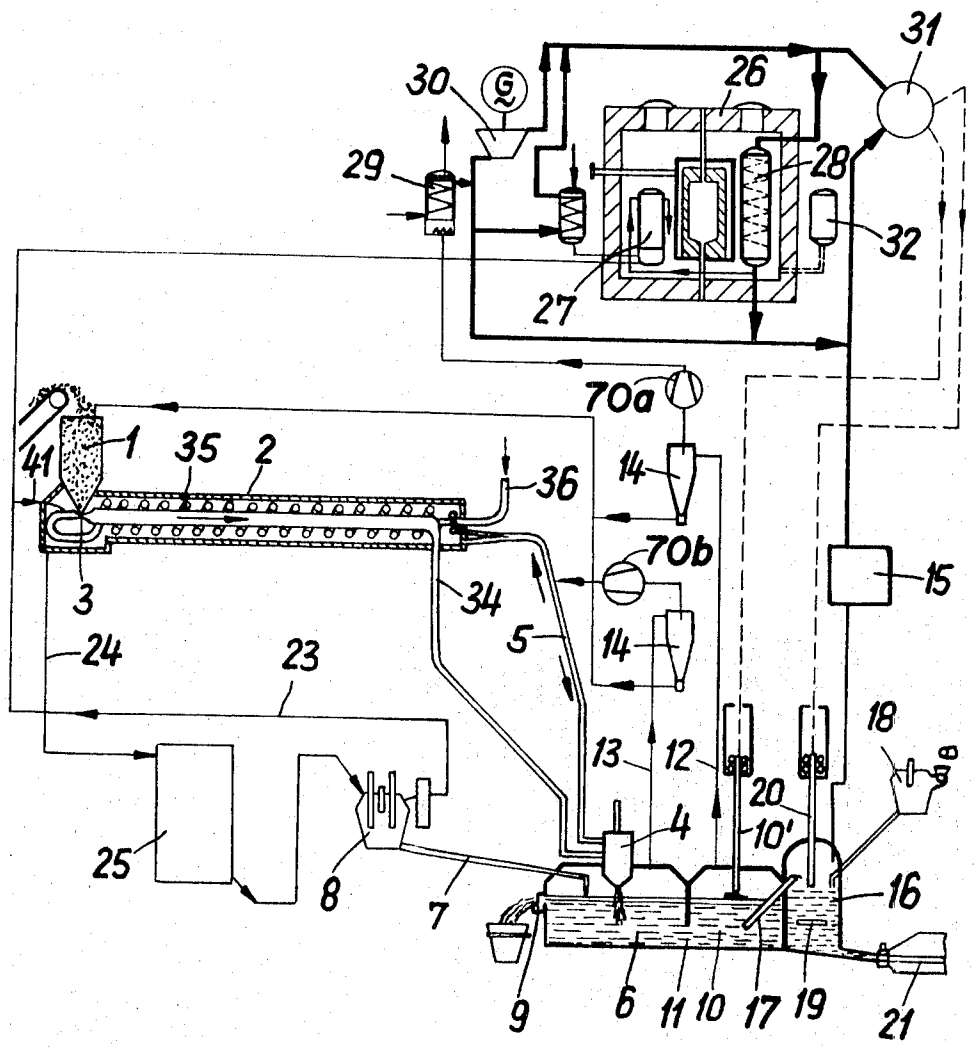


FIG. 1


31
30
G
26
29
28
32
27
70a
41
1
35
2
36
14
70b
15
3
34
5
14
24
23
18
13
12
20
4
10'
25
8
7
16
9
6
11
10
17
19
21

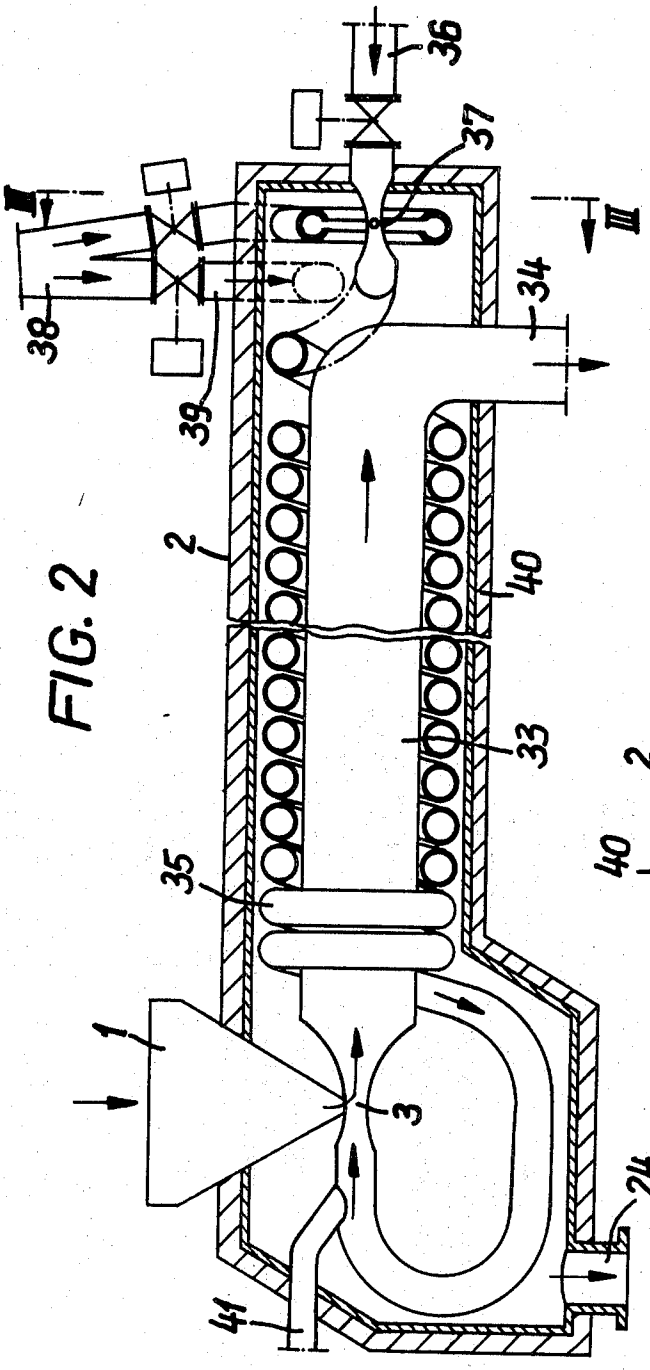


FIG. 2

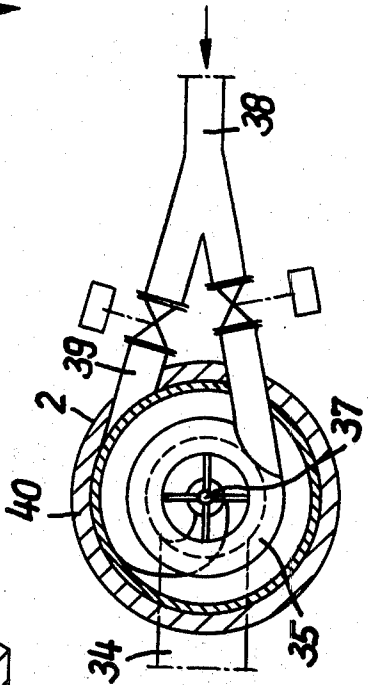


FIG. 3

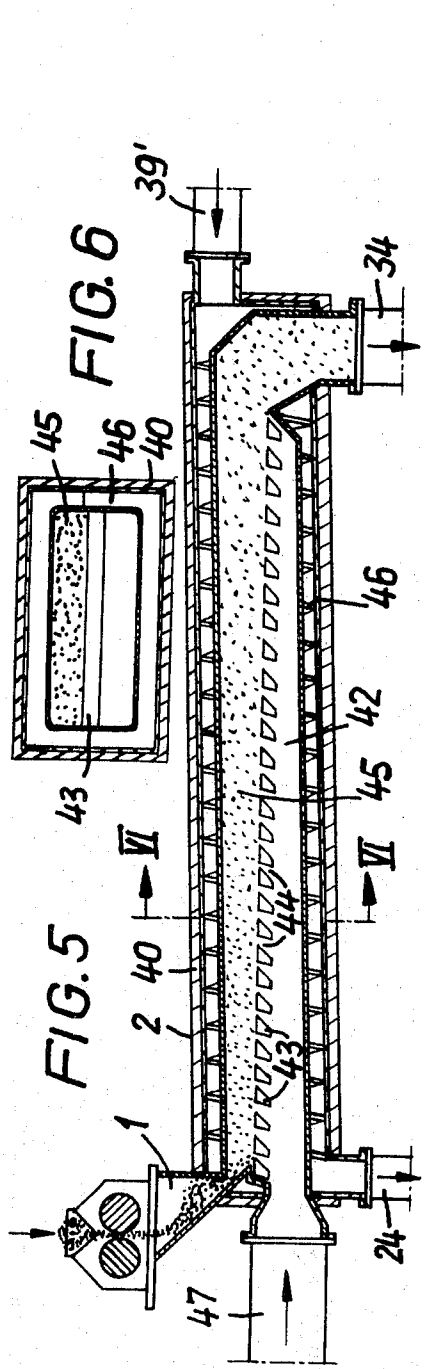


FIG. 6

FIG. 5

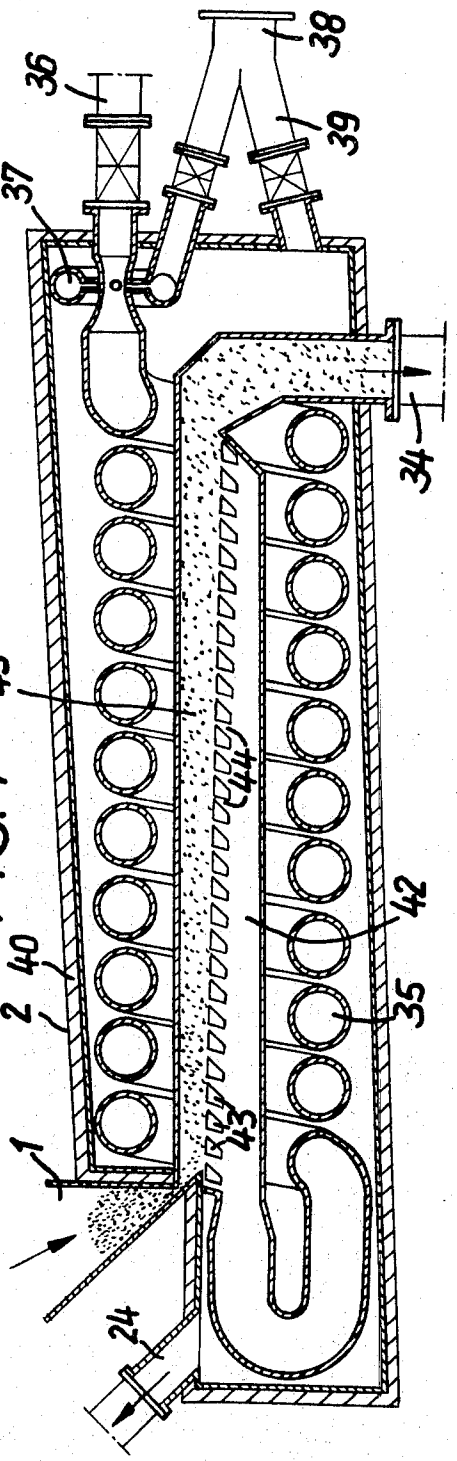


FIG. 4

FIG. 7

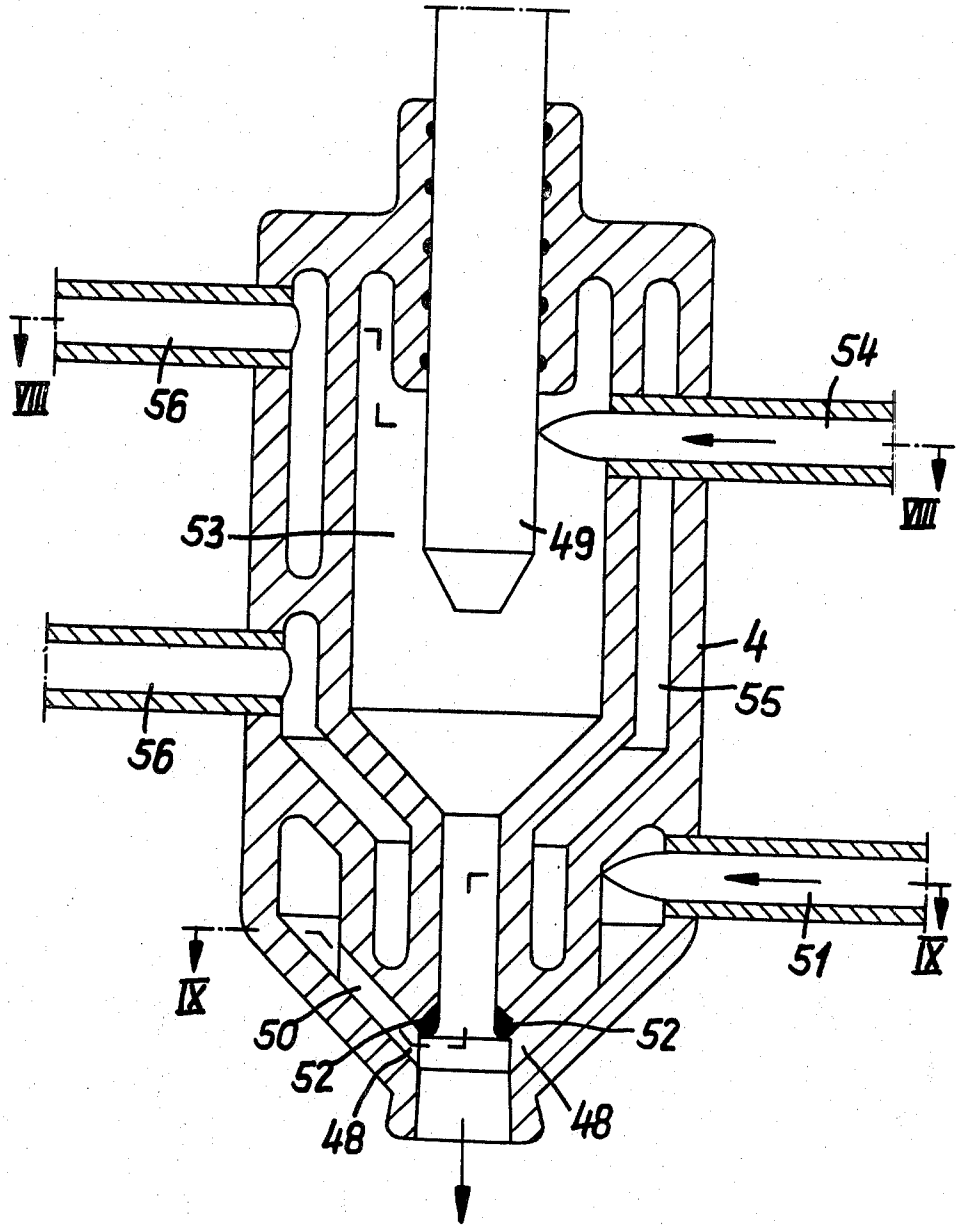


FIG. 8

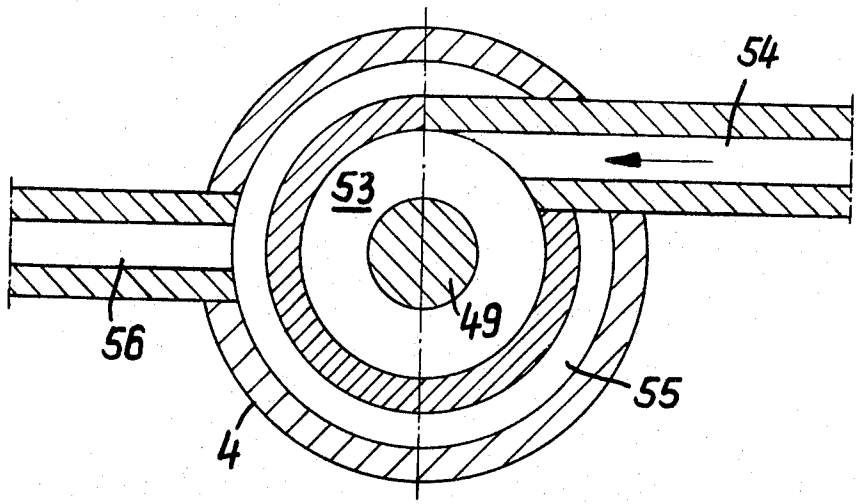


FIG. 9

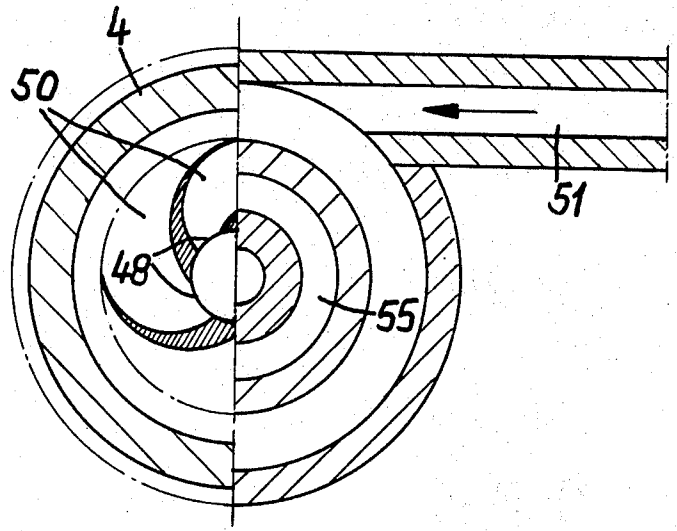
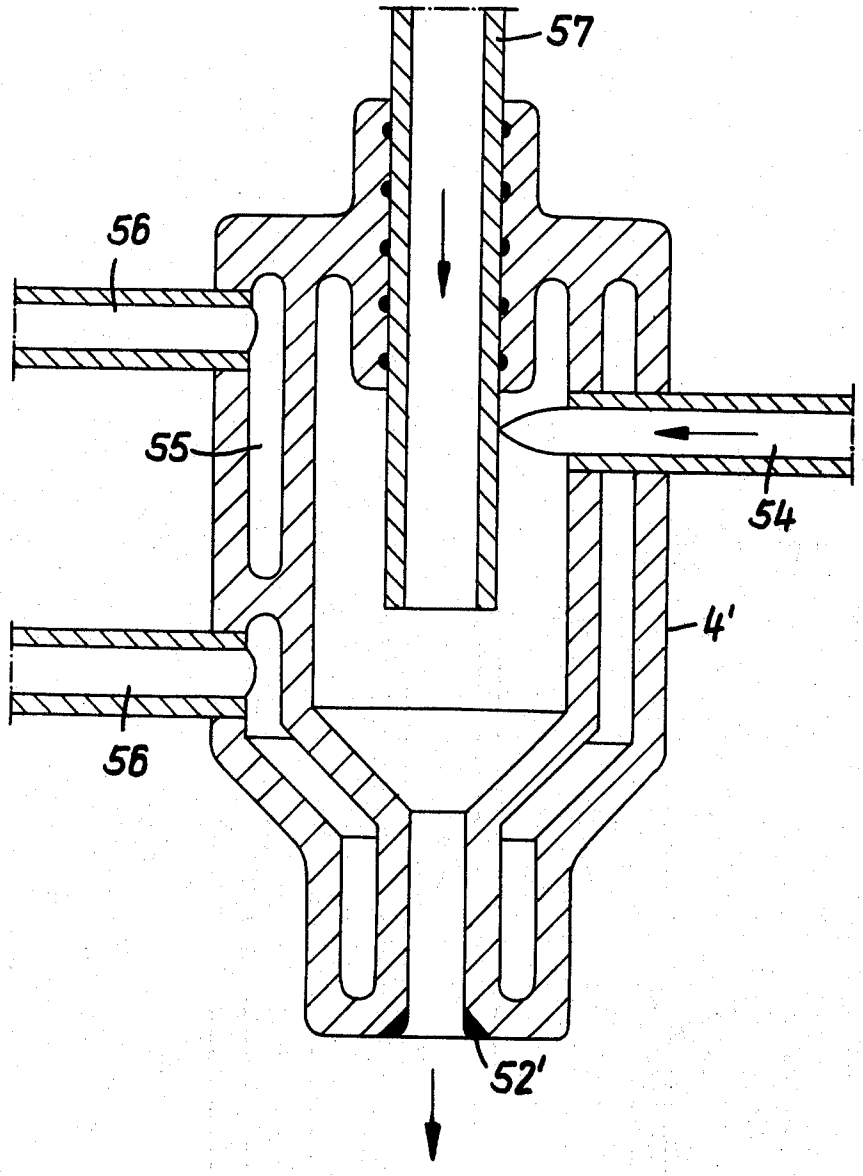


FIG. 10



METHOD FOR PRODUCING STEEL

CROSS-REFERENCE TO RELATED APPLICATION

This is a continuation-in-part application of parent application Ser. No. 240,641, filed Apr. 3, 1972 and now abandoned.

BACKGROUND OF THE INVENTION

The present invention relates to a method for making steel from finely ground rich ores using a plasma burner. The method operates continuously.

There are already known methods for making steel from ore dust of high iron content, but these methods operate to a greater or lesser degree discontinuously. Usually, the ore dust is reduced in fluidized beds using reducing gases and the resulting powder of high iron content is briquetted for further processing in a usual refining unit. The briquetting is necessary, because the iron powder would not penetrate through the slag in a refining unit, not even if it were blown onto the slag with high pressure. Here, the process is not only disadvantageous because of the interposed, uneconomical step of briquetting; the subsequent conventional refining processes operate batch-wise and thus discontinuously.

It has already been proposed a number of times that plasma burners should be used for making steel. Thus German Democratic Republic's Pat. No. 28,822, teaches equipping usual metallurgical equipment, such as the Siemens-Martin furnace, converters, and electric arc furnaces, with plasma burners for heating, and preferably for auxiliary heating. Here, the usual inert gases used for producing a plasma can be mixed with a reducing gas. Additionally, the gas can be mixed with known, powdered, reactive materials for cleaning the melt and for alloying.

Similar technique is taught in U.S. Pat. No. 3,347,766. The reducing gas fed to the inert gas plasma is conducted into the slag of a metal bath in a hearth furnace in a highly reactive condition and is thus supposed to accelerate the refining process. The anode of the plasma burner is arranged in the hearth furnace, thus meaning significantly larger costs and difficulties in plasma stream regulation because of the different bath and slag heights.

The JOURNAL OF METALS for January, 1961, describes in a general way at pages 51 to 54 various possible applications for plasma burners in metallurgy. Thus, they are suggested for serving as heat sources in usual melting and refining furnaces. It is further indicated that a reduction of difficulty reducible metal oxides is possible in a plasma stream containing carbon and that a reoxidation of the resulting metals can be prevented.

SUMMARY OF THE INVENTION

An object of the present invention, therefore, is to provide a method for making steel from finely ground, rich iron ores using a plasma burner and operating continuously from ore to finished steel, which method reduces heat losses and makes possible a plant of low cost and small size.

This as well as other objects which will become apparent in the discussion that follows are achieved, according to the present invention, by a method for reducing iron ore dust, comprising forming the dust into a cloud, transporting the cloud in reducing gas, reacting the cloud with the gas for enriching the dust, and introducing the transported cloud into the plasma stream of a plasma burner whose plasma stream is penetrating into the bath of a melting furnace.

GENERAL ASPECTS OF THE INVENTION

The present invention lies first of all in the forming of the charged ore into a cloud of dust, transporting the cloud by means of reducing gas in a suitably heated device, while simultaneously enriching the ore, and finally feeding the ore into the plasma stream of a plasma burner whose plasma stream is penetrating into the bath of a melting hearth. If need be, the ore can be finally transformed into steel continuously in at least one refining unit connected to the melting hearth.

The invention provides the advantage that the continuously resulting, finished steel can be continuously submitted to further working, especially in a continuous casting mold and rolling mill trains following such a mold.

The iron oxide recovered from the exhaust gases of the refining units and the melting hearth, so-called LD-dust, can be fed back into the process and thus need not represent a loss.

The reduction of the ore begun in the heated transport device is continued in the plasma stream of the plasma burner and finished in the melting hearth or following refining unit.

In a further development of the invention, a cracked gas is used as the reducing gas. This cracked gas is produced by means of nuclear reactor heat loss in a heated cracking tube from coal, oil, or natural gas. In this way, it is possible to combine the basic process of the invention extremely economically with a nuclear power plant.

In another development of the invention, the reducing gas is a cracked gas produced from natural gas and furnace exhaust gas in a cracking tube heated by the heat fed to the heated transport device. This gives a further improvement in the heat utilization.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic view of a steel producing installation according to the present invention.

FIG. 2 illustrates the transport section of FIG. 1 in greater detail.

FIG. 3 is a section viewed on the cutting plane III—III of FIG. 2.

FIGS. 4 and 5 are modified transport sections.

FIG. 6 is a section viewed on the cutting plane VI—VI of FIG. 5.

FIG. 7 is an elevational section of a plasma burner for use in the present invention.

FIG. 8 is a section viewed on the cutting plane VIII—VIII of FIG. 7.

FIG. 9 is a section viewed on the cutting plane IX—IX of FIG. 7.

FIG. 10 is an elevational section of a plasma burner for use in the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Firstly with reference to FIG. 1, finely ground ore coming continuously from a mill and having preferably a minimum iron content of 63% by weight is loaded into a feed hopper 1 for feeding the transport section 2. The finely ground ore has preferably a size in the

range suitable for fluidized bed reduction processes, e.g., 40 microns. The lower end of hopper 1 opens into a device 3 having the structure of an atomizer, where the finely ground ore is formed into a cloud of dust by means of hot reducing gas blown through the atomizer device 3. The reducing gas then transports the cloud of dust further in the direction of the longitudinal axis of the transport section 2.

The ore dust is enriched at the same time as it is being transported in the transport section, which is maintained at a reducing temperature by heat transferred from hot gas. The enrichment may be by any of the fluidized-bed reduction processes such as H-Iron, Nu-Iron, and Esso-Fior. The iron content of the ore dust as it leaves transport section 2 is preferably in the range of 93 to 97 weight-percent. Finally, the ore dust is conducted into the plasma stream of an electric arc plasma burner 4, which is connected as close as possible to the end of the transport section 2. The flow rates of dust and reducing gas, are determined by the thermodynamic and kinetic conditions of the reduction process in the transport section, i.e., conditions such as reduction velocity, temperature range, pressure and particle size of the ore. The particular plasma stream used for the present invention is preferably not affected by variations in the flow rates.

For the purpose of forming the plasma stream of the plasma burner, furnace exhaust gas is conducted through lower cleaner 14, compressor 70*b*, and pipeline 5 to the electric arc plasma burner 4. The exhaust gas is thus first cleaned, in order to prevent short-circuit-causing bridges.

The cloud of dust is sucked into the plasma stream as a result of the pressure drop caused by the movement of the stream. The dust is strongly heated once in the stream, and is further reduced to a small extent. The dust particles are turned into liquid particles and pass into a liquid metal bath of a melting hearth 6 along with the plasma stream which penetrates into the bath. The plasma stream, which maintains the temperature of the ore particles at about 1,700° C, is adjusted such that it penetrates into the melt far enough, for example a few millimeters, to provide a sufficient and thorough mixing of the melt. Since the reduced ore dust never comes in contact with oxygen all the way down into the melt, a reoxidation of the melted particles is prevented.

The plasma arc temperature depends primarily on the particular plasma gas being used, and on the place where the temperature is measured in the arc. The temperature can reach up to 20,000° C. At the point of penetration of the plasma stream into the bath, the temperature shall not, however, exceed electric arc temperature since otherwise too much material is evaporated.

The technology of the plasma arc per se has been well developed for the welding and cutting of metals and for the space reentry simulation experiments of NASA.

The melt in the melting hearth 6 is continuously fed liquid calcium carbide of low acetylene rate through pipeline 7 coming from a calcium carbide oven 8 where the calcium carbide is melted. This slag-building additive, which is a mixture of calcium carbide and calcium oxide producing only small quantities of acetylene gas when mixed with water, serves primarily for a good desulphurizing of the melt; it can also serve simultaneously for raising the carbon content of the melt. For purpose of renewing the slag, the melting hearth is provided at the level of the top of the bath with at least one overflow cup closure 9, in the form of a skimmer, through which excess slag is continuously removed. Calcium carbide smelting practice is known per se and is in worldwide use in electric submerged arc furnaces.

Preferred technique for obtaining a suitable calcium carbide in oven 8 is melting down a mixture of 36% by weight of calcium carbide and 64% by weight calcium oxide in temperature range of theoretically 1,600°–1,800° C depending on the desired viscosity of the melt. One to four weight-percent of the resulting calcium carbide is added to the melt in hearth 6, depending on the sulphur content of the melt.

Since there is a small amount of refining which takes place in the melting hearth 6 due to the action of the plasma stream, the process can be ended here, should a lower quality steel be acceptable. Sometimes, no undesirable elements get into the melt on hearth 6, and especially then it is possible to end the process here. The characteristics of the melt in the hearth 6 are mainly determined by the materials charged into the hearth, by their chemical compositions (i.e., their content of sulphur and phosphorus) and gangue, and by the composition of the plasma gas. Plasma gases consisting mostly of hydrogen and nitrogen can lead to a hydrogenation and nitrogenation of the melt; this is undesirable.

Exemplary for the hearth 6 practice per se is the melting down of sponge iron in the electric arc furnace practice at the Mexican Hylsa works.

For the purpose of making steels of higher quality by removing tramp elements, one or more refining units are connected right at the outlet of the melting hearth. Suitable refining processes are all those which can be carried out in hearth furnaces. In the example of FIG. 1, the refining unit is a furnace 10 of the type including the blowing of oxygen onto the steel to be refined. In one example of the invention, steel qualitites at least as good as those obtained in open hearth practice result. Furnace 10 is in communication with the melting hearth 6 by way of a channel 11 located in the floor of the furnace. Molten metal from hearth 6 continuously drains through this channel into furnace 10. Furnace 10 refines continuously in conventional manner by means of an oxygen lance 10′ used for blowing oxygen onto the melt. Lime dust is added for slag formation. A molten steel product is continuously withdrawn from furnace 10. The LD-dust coming off in the exhaust duct 12 connected to furnace 10 and in the corresponding exhaust duct 13 of the melting hearth 6 is collected in the gas-cleaning installation 14 and then fed into the feed hopper 1. The used slag in furnace 10 is likewise continuously withdrawn. It may be advantageous for the continuous operation of the process to divide the melting hearth 6 and the refining unit by means of dividing walls or chicanes running transversely to the flow direction of the melt.

For quieting and alloying the molten steel, it is advantageous to connect an alloying hearth 16 to the refining unit. Vacuum equipment 15 communicates with hearth 16. Molten steel coming from the oxygen-blowing furnace 10 moves through a suction tube 17 and reaches the alloying hearth in the form of fine droplets which distributed themselves over the surface of the alloying hearth bath. The alloying components melted in a ferro-alloying furnace 18 and continuously fed to the al-

loying hearth 16 are metered on the basis of continuously measured parameters of steel quality, for example on the basis of spectral analyses. The bath of the alloying hearth 16 is divided by a horizontally lying dividing wall 19 into an upper mixing zone and a lower quieting zone. Mixing is accomplished by a stream of nitrogen blown in through lance 20.

The molten, finished steel flows into the mold of a continuous casting installation 21 and is then worked further in continuous rolling trains.

It is preferred that the reducing gas be primarily cracked gas produced from natural gas and furnace exhaust gas in a cracking tube 35 which winds within the heated device over its transport section 2. The furnace exhaust gas is mostly carbon dioxide and is thus partly moving as a recirculating agent. The heat in the exhaust gas contributes to the cracking and is thus made directly useful for the process. The following formula gives a rough idea of the manner in which the process operates:

$$4Fe_2O_3+3CH_4+3CO_2 \longrightarrow 8Fe+3CO_2+(3CO_2+6H_2O),$$

where the quantity in parentheses represents the portion of the exhaust gas which is not recirculated. Thus, theoretically, half of the carbon dioxide in the exhaust is recirculated. These values can of course not be obtained practically speaking, since an excess of reducing gas must be used. The exhaust gas contains more or less large amounts of carbon monoxide; because this carbon monoxide is produced continuously in the process of the invention, it can be well used in a burner plant, for example for producing steam. Another, remaining part of the furnace exhaust gases is utilized for heating the device containing the transport section 2.

Reducing gas containing about 85 volume-percent carbon monoxide, remainder hydrogen, and having a high degree of purity is produced in quantity in the calcium carbide oven 8 and a direct introducing of this through pipelines 23 and 41 into the transport section is advantageous in all circumstances. Furnace exhaust gas used for heating the heated device with transport section 2 leaves the heated device through pipeline 24 and is brought by this pipeline to the lime oven 25.

It is especially advantageous when the process of the present invention includes utilization of heat from a nuclear reactor installation. The reducing gas can then be produced from coal, oil, or natural gas in a cracking tube 27 built into a reactor 26. The cracking tube built into the heated device with transport section 2 can then be eliminated, if desired. Furthermore, the process of the invention can be begun using hot helium gas for the purpose of heating the heated device containing the transport section 2. The hot helium gas is used until a sufficient quantity of exhaust gas is available to take over the function of the helium gas. The exhaust gas eventually drives the helium out of the heated device. The small amount of helium that is lost due to its being driven out by the exhaust gas is unimportant. Furthermore, a steam superheater 29 can be placed before a steam producer 28 built into the reactor 26 and the steam superheater can be run using furnace exhaust gas forwarded from upper cleaner 14 by the compressor 70*a*. In the steam circuit are located, firstly, a turbine 30 running an alternating electrical current generator G and, secondly, a plant 31 for producing the requisite oxygen and nitrogen. Additionally connected to the reactor 26 is a helium supplier 32.

Instead of including a reactor in the process, it is also possible to make other integrated facilities. To this end, it is especially advantageous that the exhaust gases come from the process of the invention in essentially constant quantity. This is advantageous for all possibilites for using the exhaust gases. A not inconsiderable quantity of steam is, furthermore, produced from the cooling water fed to the plasma burner and this can be directed into the steam circuit.

The transport section 2 illustrated in FIG. 1 will now be explained in further detail on the basis of FIGS. 2 and 3. As above explained, the finely ground, heated and dried ore moves into the atomizing device 3 from feed hopper 1 and is formed into a cloud of dust. From the atomizing device, the ore dust is maintained as a cloud in the transport section 2, which is here in the form of a tube-shaped turbulence bed 33, by means of reducing gas and is transported onwards, until it leaves the transport section 2, in enriched condition, through the exit end 34. Exit end 34 is in communication with the electric arc plasma burner 4. Surrounding the tube-shaped turbulence section 33 is a cracking tube 35. The cracking tube winds helically around the section 33. Natural gas is introduced into cracking tube 35 at its inlet 36. The natural gas is mixed with carbon dioxide from the furnace exhaust gases. The carbon dioxide comes in through pipeline 38 and is mixed with the natural gas at ring nozzle 37. The resulting mixture is cracked in the cracking tube to a reducing gas whose reducing components consist essentially of carbon monoxide and hydrogen. The heat required for the cracking and for maintaining a reducing temperature in the transport section 2 is transferred to the transport section 2 by hot furnace exhaust gases entering through branch 39 from pipeline 38. The temperature in the transport section is further supported by an insulating jacket 40. The still hot furnace exhaust gases leave the transport section 2 through pipeline 24 leading to lime oven 25. Pipeline 41 leads into the downstream end of the cracking tube 35, just before the nozzle section of the atomizer device 3 for the purpose of introducing as a component of the reducing gas the reducing gases from the calcium carbide oven 8 and for introducing gases which have been produced in cracking tube 27 of reactor 26, if the reactor is being used in the process.

The heated device, with transport section, illustrated in FIG. 4 is constructed similarly to that of FIG. 2. Instead of a tube-shaped turbulence bed 33, there is here a fluidizing bed that transports the cloud of ore dust. The reducing gas moves through nozzles 44 located between beams 43 over the entire length of the transport section. The nozzles 44 are tilted downstream for the purpose of moving the one particles continuously onwards. The reducing gas thus serves for forming and transporting the cloud of ore dust and, in the actual reaction chamber 45 of the bed, enriches the ore.

The heated device, with transport section 2, of FIGS. 5 and 6 likewise uses a fluidizing bed 42. Helical channel 46 conducts heating gas entering at channel end 39'. Pipeline 47 serves for introducing the reducing gas, which in this case is preferably made in a nuclear reactor as above-described.

Referring now to FIGS. 7 to 9, the electric arc plasma burner 4 has at its outlet region pairs of outlet openings 48. The openings 48 of any given pair lie opposite one

another and face the channel through which the plasma stream from cathode 49 is moving, on its way to the melt. Openings 48 are the mouths of spiral-shaped channels 50. Tangentially feeding into channels 50 is inlet pipeline 51 communicating with exit end 34 of FIGS. 1 to 5 for the mixed ore dust and reducing gas. Here, the ore dust reaches the plasma stream laterally.

Immediately over the outlet openings 48 is the anode 52 of the plasma burner. The cleaned furnace exhaust gas used for producing the plasma is fed to the burner chamber 53 through a channel 54 likewise approaching tangentially. A hollow portion 55 is connected with a cooling water circuit 56.

The annular electrode electric arc plasma burner 4' of FIG. 10, whose electrodes are spaced from one another along an axis of plasma stream flow, has a tube-shaped cathode 57, instead of the solid cathode 49. Anode 52' of one or more parts is situated right at the end where the plasma exits. The mixture of ore dust and gas is introduced into the plasma burner through the tube-shaped cathode 57 in the direction of the arrow and is sucked into the plasma stream forming on the lower end of the cathode. This form of the plasma burner is especially advantageous, because it may be built very easily and does not have any constrictions which might get stopped up.

Both embodiments of the plasma burner can have a three-phase or rotational current superimposed on them. For ionizing the gas, the burners are started up with direct current and high power, and then the three-phase current is brought in. The cathode and anode then have three poles, or else a multiple of three poles. The electric arc plasma burners 4 and 4' can be made of ceramic materials of high heat resistance. Then a special insulating of the cathodes and anodes becomes unnecessary.

The method of the present invention can be made completely automatic in simple manner and makes possible many variations in the producing of the plasma stream.

It will be understood that the above description of the present invention is susceptible to various modifications, changes and adaptations, and the same are intended to be comprehended within the meaning and range of equivalents of the appended claims.

We claim:

1. A method for reducing iron ore dust, comprising
   a. forming said dust into a cloud;
   b. transporting said cloud in reducing gas to a plasma stream of a plasma burner;
   c. reacting said cloud with said reducing gas during transporting to enrich said dust and reduce said ore;
   d. introducing the transported cloud containing reduced ore into the plasma stream of a plasma burner to melt the reduced ore and form liquid particles; and
   e. directing the plasma stream to penetrate into a liquid metal bath of a melting furnace to pass said liquid particles into and mix the liquid metal bath.

2. A method as claimed in claim 1, further comprising continuously draining metal from said bath and subjecting the drained metal to further refining.

3. A method as claimed in claim 1, further comprising producing said reducing gas by transferring heat from a nuclear reactor to a cracking tube containing a material selected from the group consisting of coal, oil, and natural gas.

4. A method as claimed in claim 1, further comprising producing said reducing gas by transferring heat used for carrying out the step of reacting into a cracking tube containing natural gas and exhaust gas.

5. A method as claimed in claim 1, wherein the step of reacting is carried out by heating said gas and dust with heat transferred from hot exhaust gas.

6. A method as claimed in claim 1, further comprising continuously feeding to said bath a liquid slag-building means and continuously removing slag from the top of said bath.

7. A method as claimed in claim 6, wherein said slag-building means is calcium carbide.

8. A method as claimed in claim 1, wherein said reducing gas is directed at said dust for effecting the forming of the dust into a cloud.

9. A method as claimed in claim 1, wherein said iron ore dust initially contains at least 63% by weight iron.

* * * * *