This invention relates to the production of a metal from a finely divided reducible compound thereof. More specifically, this invention relates to a process for the production of molten iron which consists essentially of reduction of iron ore in a fluidized bed followed by melting the reduced powdered iron in an electric furnace. The process of this invention advantageously forms one step in the production of steel in areas where generated or natural gas fuels and inexpensive electric power are available, but where metallurgical grade cooking coals are unavailable.

In conventional steel-making practice, iron ore is first reduced in the blast furnace to produce pig iron which subsequently, along with scrap, becomes the charge to the steel-making furnace, namely, the open-hearth, Bessemer, or electric furnace, to produce various grades of finished steel. Successful operation of the conventional blast furnace is largely dependent upon the quality of the fuel. In the blast furnace, coke serves as the fuel, reducing agent, and most important supports the burden and maintains it permeable to the passage of gas in the higher temperature zones of the furnace. Thus, metallurgical coke must be of adequate size and have sufficient strength to resist breakdown in the furnace. With the growing shortages of high grade metallurgical coke, efforts have been made in recent years to develop a reducing process which will not be so particular with respect to the physical properties of the reducing material. Reduction of iron ore has been tried in various types of equipment such as rotating kilns, Harrewes roasters, various types of conveyors, crucibles, shaft furnaces, and even so-called bubble hearth roasters. None of these so-called direct or alternative reduction methods have been economically successful due to the fact that in all cases the nature of the producing unit limits the producing capacity. This means that in order to obtain an equivalent producing capacity, multiple producing units are required which results in high investment and operating costs, as compared with the conventional blast furnace. In the steel industry small operations mean high costs and an alternative process is to be successful, it is necessary to develop a process and operating unit which will be equivalent in terms of capacity and cost with the coke blast furnace. Such a method is the subject of this invention.

The typical steel-making process in which the method of the present invention is an important step involves reduction of iron ore in order to produce molten iron by the method of this invention, followed by refining of the molten iron so produced in steel-making furnaces such as the open-hearth, Bessemer types, or electric furnace to produce steel.

In order to carry out this invention, the ore is first subjected to gaseous reduction in a fluidized bed with generated reducing gas or partially combusted natural gas or other hydrocarbons used as the reducing agent. Iron ore of the proper particle size distribution suitable for operation in a fluidized bed is first charged continuously to a preheating unit where it is heated by combustion of a portion of the top gas from the reducing bed. This preheating unit may advantageously be a fluidized bed, but may be any other suitable preheating unit such as a rotary kiln or a device similar to a Harrewes roaster. By this procedure the temperature of the ore is raised, preferably to about the operating temperature of the subsequent reducing fluidized bed. The preheated ore is carried by the excess top gas and is then fed to the top of the reducing fluidized bed where it contacts hot reducing gases.

The fluidized bed is established by blowing up through the bed a stream of reducing gases derived from burning with air or oxygen either liquid or gaseous fuels including those derived from solid fuels, such as producer gas. The velocity of the gas stream is controlled with reference to particle size of the ore or reduced material to set up a fluidized bed condition in which the particles are dispersed or suspended in the gas stream without excessive entrainment and carry-over of the solid particles in the gases leaving the zone of solid suspension. The preheated ore will be reduced in the solids state in the reducing bed to the extent that approximately 80-90% of the iron content of the original ore will be reduced to iron while the remaining 10-20% of the original iron content will be reduced to FeO. The reduced ore will be discharged continuously by overflow from the fluidized reducing bed. This reduced ore will be finely divided and at elevated temperatures highly pyrophoric.

This pyrophoric material discharging from the reducing bed must now be consolidated, which is carried out in accordance with the present invention by converting it to molten iron. In the preferred method of operation of this invention this finely divided reduced ore is discharged continuously into an electric arc melting furnace similar to the type used in Scandinavian countries to smelt iron ore directly to molten pig iron. This electric melting furnace is preferably operated full and designed to facilitate movement of the charge, in order to feed and maintain a high load factor on the electrodes. It will continuously receive reducing material which will be melted and the impurities slugged with suitable fluxing agents. The slag and molten iron will be periodically tapped from the furnace into ladles. The molten iron may then be refined by conventional methods to produce steel.

This invention will now be described in more detail in connection with the accompanying drawings, in which:

Fig. 1 represents a vertical view, partly in section, of suitable equipment for carrying out the procedure of this invention; and

Fig. 2 represents a vertical view, partly in section, of an alternative arrangement of part of the equipment shown in Fig. 1.

The equipment comprises three principal parts: the preheating unit 10, the fluidizing reduced bed 12, (both shown in Fig. 1) and the electric-arc melting furnace 14 (shown in Figs. 1 and 2). Associated with these parts are suitable ducts for feeding materials to various parts of the equipment and for leading products away, and also suitable separators for removing solids from gases. These are described below in connection with the description of the operation of this invention. Like numbers refer to like parts in the two figures.

In carrying out the procedure of this invention, the ore feed material is first screened or ground to establish particle size distribution suitable for operation of a fluidized bed. Although iron ores are the ones with which this invention is particularly concerned, and which will be referred to in the further description of this invention, it is to be understood that other ores which, when reduced to the metal, exhibit pyrophoric properties when
hot and finely divided, are amenable to the treatment herein described. Such other ores include, for example, other ferruginous ores, e.g., titaniferous magnetites. The ore feed material is sized as mentioned above at about minus 8 mesh and with a minimum of very fine material (minus 325 mesh), in order to minimize the tendency to carry over very fine material in the exit gas stream from the bed. This sized ore is dumped into bin 20 whence it flows via conduit 22 to preheating unit 10. In this unit it is preheated by the combustion of a portion of the low BTU, top gas from the subsequent fluidized reducing bed of unit 12. This top gas enters chamber 33 from duct 26, and passes up through distributing grate 28 into combustion chamber 30 where it burns in combination with air introduced through conduit 32. Hot combustion gases rise through grate 34, and heat and agitate the ore particles in chamber 36. These preheated ore particles then pass out through conduit 38. It will be noted that this is essentially a fluidized bed preheating treatment; however, other preheating methods and apparatus may be used within the scope of this invention. The ore particles passing out through conduit 38 emerge into reducing bed 12, where they contact reducing gas generated from the partial combustion of natural gas and other fuel introduced through conduit 40 and mixed with air which is introduced through conduit 42. The fuel is subjected to partial combustion with air in chamber 44, and the resulting reducing gas passes up through the perforated grate 46 to provide fluidized reducing zone 48.

Additional particles are fed to zone 48 via duct 50 leading from cyclonic separator 52, into which the off-gases from preheating unit 10 discharge via duct 54.

Gases discharged from bed 12 pass off via duct 56 to cyclonic separator 58, whence the separated particles pass downwardly toward melting furnace 14 and the cleaned gases pass up through duct 60. A portion of these gases passes from duct 60 into line 26 controlled by valve 62, for preheating in unit 10 as already described. The balance of these gases is discharged through duct 64 controlled by valve 66.

In the operation of the fluidized reducing bed 12, the individual particles are in a fluidized state of suspension in the gas emerging from chamber 44. In this state the particles are subject to violent agitation and extremely intimate mixing, so that for all practical purposes the composition of the bed is identical throughout. The gas velocity must be maintained at the proper level to fluidize the material and yet not carry over excessive quantities of finely divided material in the off-gas. The solid, finely divided ore fed to the bed via conduit 38 is removed continuously by overflow through conduit 68. The ore when properly fluidized may be handled in a manner similar to handling a liquid. The operating temperature in zone 48 must be sufficiently high to give adequate reaction rates. However, the temperature must be maintained below the fusion point of the reduced iron particles so that the particles do not weld together and change the fluidizing characteristics of the bed material. The chemical equilibrium stoichiometric factors must be such that enough reducing gas is produced to allow the removal of the oxygen as carbon dioxide and/or water vapor. The thermal requirements of the process must also be met so that the heat required by the reduction is supplied by preheating the reducing gas or by adequate partial combustion of the fuel in the bed or just prior to entry into the bed. Thus, in order to satisfy the thermal requirements of the integrated process, it will be preferable to preheat the ore, as in unit 10, by combustion of the portion of the off-gas from the fluidized reducing bed and also to preheat the air and combustion gases prior to entering the reducing bed. This is done in order to provide sufficient heat to meet the thermal requirements of the reduction operation, and maintain the proper temperature level in the reducing bed.

The melting of this highly pyrophoric reduced material emerging from the fluidized bed via conduit 68 is a critical step in the process of this invention. The finely divided reduced ore is of no significance and is of little use in the steel industry in powdered form, and, therefore, must be agglomerated preferably to molten iron to complete the processing of the ore. Various methods having been proposed for melting this finely divided pyrophoric reduced ore, the electric-arc smelting furnace herein described offers the best possibilities. If such a furnace is suitably designed so that a head of material was provided to force-feed the arcs, as shown in Fig. 1, the finely divided reduced material can be melted directly in such an electric-arc furnace 14. Alternatively, as shown in Fig. 2, the reduced material can be fed by a plurality of chutes to the electric-arc furnace 14, using an arrangement generally similar to that of a standard Thyssen-Hole type electric smelting furnace. It is interesting to note that an 18,000 kva. Thyssen-Hole type electric smelting furnace operating on high grade ore can produce about 185 tons per day of pig iron. Based on detailed heat balance calculations for this operation, the operation of this invention, it is found that if the reduced ore emerging from conduit 68 is subjected to the same size 18,000 kva. Thyssen-Hole furnace, about 700 tons of pig iron per day can be produced.

The finely divided reduced material discharged from conduit 68, as well as from separator 58, into electric melting furnace 14 is primarily iron with a minor amount of ferrous oxide, FeO, in the case of iron ore fed at bin 20. More specifically, about 80 to 90 percent of the iron oxide in the ore is reduced to iron, while the remaining 10 to 20 percent is reduced to FeO. The furnace 14, in the embodiment shown in Fig. 1, is provided with a stack 70 high enough to provide a head of material adequate to force-feed the electrodes 72. Preferably the walls of stack 70 diverge downwardly, to minimize any tendency of the particles to stick to the walls. By-pass line 73 is provided to conduct waste gases from furnace 14 back to separator 58.

Another arrangement for avoiding such sticking is to use multiple chutes 74 as shown in Fig. 2. These may be fed from a circular hopper 76 which is provided with any suitable distributing means for spreading the material around the circumference of hopper 76, e.g. a rotary distributor or a monorail conveyor, and which is fed from conduit 68. Since these chutes 74 are not pointed directly at the electrodes 72, the particles in the chutes tend not to be heated to the sticking point by heat from the electrodes.

In either the arrangement of Fig. 1 or that of Fig. 2 the reduced material passes directly to the closed electric furnace from conduit 68, without contact with the atmosphere. Such contact must be avoided, due to the pyrophoric property of the hot particles.

Molten iron and slag are produced in furnace 14, and are drawn off from the bottom thereof through openings 80 in the manner which is customary for tapping conventional electric smelting furnaces.

With a fluidized bed 48 which is 20 feet in diameter, discharging into an 18,000 kva. electric-arc furnace 14, about 500 tons of molten iron per day can be produced using a high grade of iron ore supply. Hence, this combination as herein described is capable of duplicating the capacity of a 500 ton per day conventional blast furnace, without the necessity for using the high-grade metallurgical coke which is now required in blast furnace practice.

We claim:

1. An apparatus for producing metal from finely divided reducible materials comprising a shaft having a first combustion chamber and a reaction chamber therein above said combustion chamber, a first partition having passages therethrough interposed between said combus-
tion chamber and said reaction chamber, means for introducing a combustion supporting gas and combustible gas into said combustion chamber for partial combustion therein and flow through said partition into said reaction chamber to fluidize a reducible material therein and at least partially reduce it to metal, said shaft having a second combustion chamber and a preheating chamber therein above said second combustion chamber, a second partition interposed between said second combustion chamber and said preheating chamber and having passages therethrough, means for withdrawing gas from said reaction chamber and supplying it to said second combustion chamber for combustion therein to supply heat and combustion gases to said preheating chamber to preheat and fluidize a reducible material therein, means for discharging said preheated material from said preheating chamber to said reaction zone, and means for discharging said at least partially reduced material from said reaction zone.

2. The apparatus set forth in claim 1 comprising a melting furnace connected with the means for discharging the material from said reaction zone.

3. The apparatus set forth in claim 1 comprising a melting furnace connected with the means for discharging the material from said reacting zone and a separator interposed in the means for withdrawing gas from said reaction chamber and communicating with said furnace for separating finely divided at least partially reduced material from the gas and supplying it to said furnace.

4. The apparatus set forth in claim 1 comprising an electric arc furnace having electrodes and a stack extending above said electrodes and connected with the means for discharging material from said reaction zone to provide a column of said material for feeding to said electrodes.

5. The apparatus set forth in claim 4 in which the walls of said stack diverge downwardly.

6. The apparatus set forth in claim 1 comprising an electric arc furnace having a melting chamber, electrodes extending downwardly into said melting chamber, and a stack extending above said electrodes and chamber, and connected with the means for discharging material from said reacting zone to provide a column of said material for feeding to said electrodes.

7. The apparatus set forth in claim 1 comprising a melting furnace connected with the means for discharging the material from said reacting zone, said furnace having electrodes and a stack extending above said electrodes for maintaining a head of said at least partially reduced material for feeding said electrodes, and a separator interposed in the means for withdrawing gas from said reaction chamber and communicating with said stack for separating finely divided at least partially reduced material from the gas and supplying it to said furnace.

8. A process for the production of a metal from finely divided particles of a reducible compound thereof, which comprises preheating said particles in a preheating zone, conducting said preheated particles to a reducing zone wherein said particles are suspended in a stream of reducing gas at a temperature and for a time sufficient to reduce the major part of said particles to metal, the conditions in said reducing zone being those of a fluidized reducing bed, introducing gases emerging from said reducing zone into a combustion zone intermediate said preheating and reducing zones, burning said gases in said combustion zone and introducing the combustion products into said preheating zone to heat the particles therein and thereafter consolidating the hot reduced particles into molten metal while maintaining the particles out-of-contact with the atmosphere.

9. A process for the production of a metal from finely divided particles of a reducible compound thereof, which comprises preheating said particles in a preheating zone, conducting said preheated particles to a reducing zone wherein said particles are suspended in a stream of reducing gas at a temperature and for a time sufficient to reduce the major part of said particles to metal, the conditions in said reducing zone being those of a fluidized reducing bed, introducing the gases emerging from the reducing zone into a combustion zone intermediate said preheating and reducing zones, burning said gases in said combustion zone and introducing the combustion products into the preheating zone to heat said particles therein, and thereafter consolidating the hot reduced particles while maintaining the particles out-of-contact with the atmosphere.

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