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FLUIDIZED IRON ORE REDUCTION PROCESS AND APPARATUS

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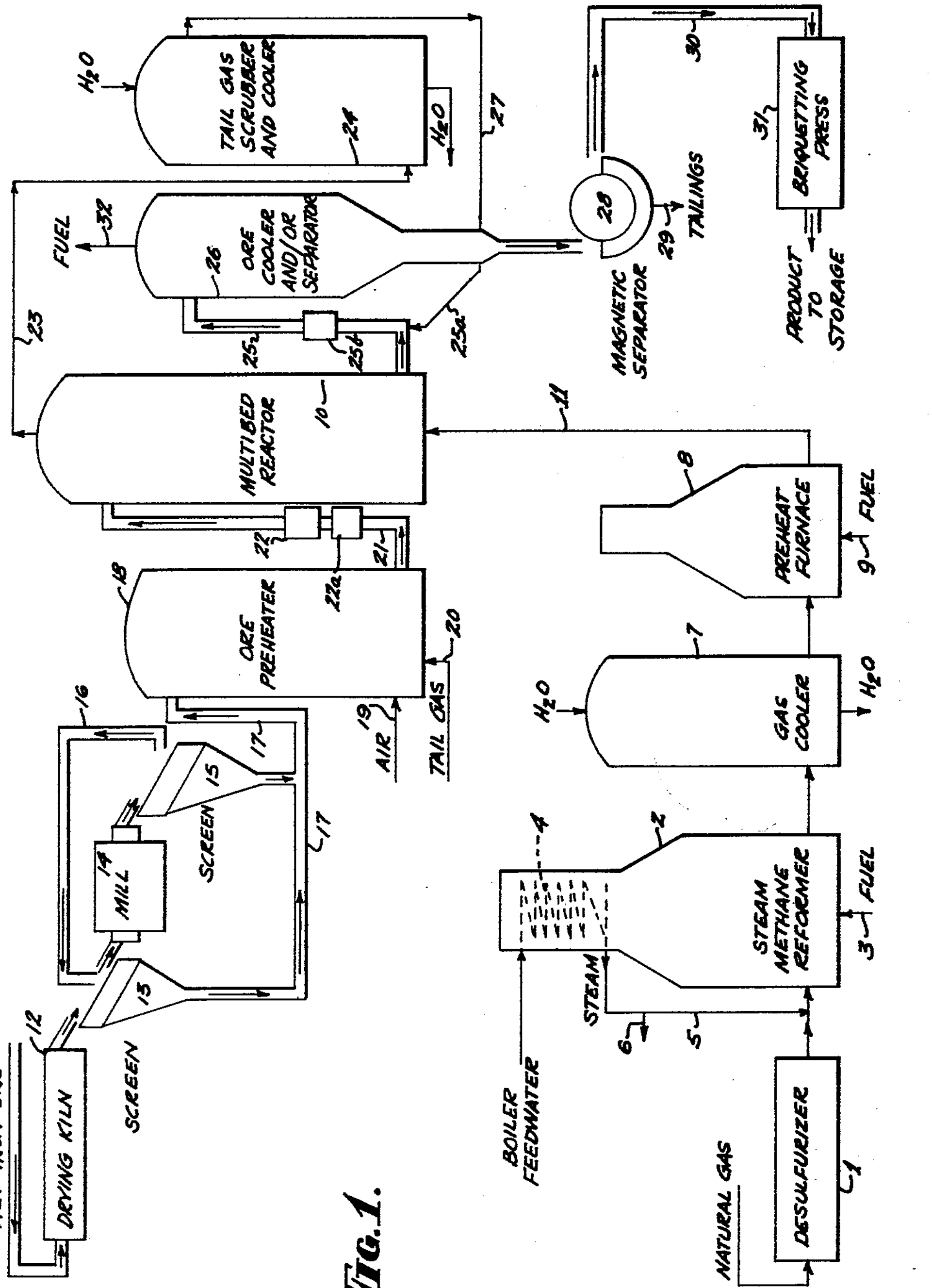

FIG. 1.

INVENTORS.
THEODORE F. OLT,
WILLIAM E. MARSHALL,
SAMUEL A. BELL,
BY
Allen & Allen
ATTORNEYS.

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FLUIDIZED IRON ORE REDUCTION PROCESS AND APPARATUS

Theodore F. Olt, William E. Marshall, and Samuel A. Bell, Middletown, Ohio, assignors to Armco Steel Corporation, Middletown, Ohio, a corporation of Ohio

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The blast furnace is still the most economical means for smelting iron in locations where coking coal and good quality iron ore in lump form are available without excessive transportation costs. Not all locations have these advantages; and additional problems are presented by the growing cost of lump iron ore, and the increasing availability of ore substances which, while high in iron (before or after beneficiation), are nevertheless in a finely divided form unsuitable for use in the blast furnace. Much work has been done in an endeavor to convert such ores or ore derivatives into coherent masses of a size which will not be carried out of the furnace with the blast.

There are locations where a supply of coking coal is not available, but where a gaseous fuel such as natural gas is plentiful and cheap, and where ores may be obtained (especially where finely divided) at moderate cost. These considerations have led to substantial research into ways of reducing iron ores in fluidized-solids reactors by means of reducing gases. Various procedures have been developed, including ones in which the processing gases are recirculated and treated in a closed recirculatory system, and including those in which the processing gases are essentially sent through the reactor a single time only.

Processes of the first type generally require a very large capital outlay, especially since it is necessary to treat the gases both inside and outside the recirculatory system. Processes of the second type have also generally required a large capital outlay, and they have the further disadvantage of producing large quantities of tail gases which must be used or disposed of elsewhere.

It is a basic object of this invention to provide a procedure of the second type which is higher in efficiency and therefore lower in cost than other procedures of the type for various reasons but especially because all of the combustible values of the gases employed in it are utilized in the process itself.

It is also a basic object of the invention to provide an apparatus for the purpose described which will involve less capital outlay per unit of iron produced than has been possible hitherto.

These and other objects of the invention, which will be set forth hereinafter or which will be apparent to the skilled worker in the art upon reading these specifications, are accomplished by that procedure and in the use of that apparatus of which an exemplary embodiment will now be described. The drawing is a diagrammatic representation of the apparatus assembly. The entire description which follows is intended to be taken as an example of the practice of the invention in the best form known to the inventors.

The process involves the use of gaseous fuel under pressure. The fuel will normally be natural gas consisting essentially of methane, although if available other hydrocarbon gases may be employed such as ethane, butane, propane, and mixtures.

It is desirable to maintain in the reactor a pressure of substantially 25 to 100 p.s.i.a. Natural gas is obtainable under these pressures; but the pressure of any available gas can be increased by the use of a pump. With some natural gases it is desirable to pass them first

through a desulfurizer indicated in the drawing at **1**. The desulfurizer may be of any of the types known in the art such as, but without limitation, a desulfurizer employing oxide of iron.

The pressurized gas is next sent through a steam-methane reformer **2**, employing a catalyst as well known in the art. Fuel entering at **3** is burned to heat the gases in the reformer and to provide the required endothermic heat of reaction. Coils of tubing **4** in the upper part of the reformer constitute a boiler. When water is introduced into the coils, steam is generated, some of which is sent to the reformer with the natural gas through a conduit **5**. Excess steam can be drawn off at **6** and used for heating or the production of power.

In the steam-methane reformer, the natural gas is converted into gases having a high reducing potential as respects iron oxide at the proper temperature providing the moisture content is low enough. The most effective way of drying the gases is by means of a gas cooler **7** in which the gases are cooled by means of water to a temperature of about 100° F. with consequent condensation of moisture. A typical but non-limting gas composition after cooling consists of 6.9% CO_2, 15.1% CO, 70.9% H_2, 0.8% H_2O, 6.2% CH_4, and 0.1% N_2.

It is necessary to reheat the processing gas to a temperature of about 1600° F. before it is sent to the reactor. For this purpose there is shown in the drawing a preheating furnace **8** utilizing fuel entering at **9**. The gases are carried to a reactor **10** through conduit means **11**.

The finely divided iron ore which is usually received in a damp or wet condition is passed first through a drying kiln **12** and then over a screen **13**. Any ore materials which cannot pass the screen are sent through a mill **14** for crushing, and are delivered to a second screen **15**. Any suitable mill may be employed for crushing, including rod mills, ball mills, swing-hammer mills and the like. There is a return **16** for over-sized materials from the second screen **15** to the entrance side of the mill. Only those ore materials which are capable of passing the screens are delivered by a conduit **17** to an ore preheater **18**. The mesh sizes of the screens may be chosen by the skilled worker in the light of the fluidization conditions to be encountered. Twenty mesh screens may usually be used; but larger or smaller mesh sizes may be chosen. In the ore preheater, in which the finely divided ore substances are subjected to continuous agitation, or to fluidization, the materials are heated to a temperature of about 1100–1300° F. by the direct combustion of a fuel with air. Air is shown entering at **19** and fuel at **20**. The preheated ore is dedelivered by a suitable conduit or conduits **21** to the upper part of the reactor **10**. The delivery means includes one or more lock hoppers **22**, the purpose of which is to pressurize the heated ore so as to convey it into the reactor. Any suitable gas stripper *22a* may be inserted between the ore preheater and lock hoppers to prevent the reactor atmosphere from becoming contaminated with the atmosphere in the ore preheater. The atmosphere in the reactor is strongly reducing, whereas the atmosphere in the ore preheater is usually oxidizing, inasmuch as complete combusition of the fuel is desired.

Where in the drawings the ore materials are indicated as delivered by conduit means, it will be understood that these may include any suitable conveying and lifting mechanisms, whether mechanical (such as bucket elevators) or gas pressure delivery means, and are also inclusive of gravitational delivery means.

The treated gases, as has been indicated, enter the reactor **10** at a temperature usually between 1400° and 1700° F. A single multi-bed reactor has been indicated in the drawing. There may be more than one of such reactors, or single-bed reactors connected in parallel or in series may be employed. In some instances fluidizing devices operating on the principle of cyclone separators may be used. The essential thing is that the reducing gases at the proper temperature shall come intimately into contact with all portions of the ore substances in the reactors or reactor system so that efficient reduction can take place.

The tail gases from the reactor are carried by a conduit 23 to a cooler 24 which again may be a cooler employing water. The cooled gases will be employed to cool the ore from the reactor 10. The reduced ore substances are shown as carried by a conduit 25 to an ore cooler 26. The action of the gas cooler 24 will be not only to cool the tail gases to the point where they can be used to cool the ore to a temperature below the reoxidation temperature, but also to remove from the tail gases moisture picked up during the reduction. Thus the cooled gases, at a temperature of about 100° F., while not strongly reducing will at least be neutral so as to protect the reduced materials from reoxidation.

The ore cooler 26 may be a fluidizing apparatus of any of the kinds mentioned above, the object being to bring the hot reduced materials into intimate contact with the cool and essentially inert washed gases. The ore will be adequately cooled if intimately admixed with a sufficient volume of the cooled gases; and this may be done in a variety of ways. One way is to mix the gas and the reduced ore substances in the conduit 25, to which end a conduit *25a* is shown in the drawing to convey the cooled gases to the conduit 25. A lock hopper *25b* may be included to permit reduction of the gas pressure on the ore without affecting the pressure in the reactor; and in the event the ore is cooled by mixing the gases with it in a conduit-type apparatus such as 25, the apparatus 26 may be considered as a cyclone separator or the like acting to separate the reduced material from the gas stream.

The minimum temperature of reoxidation will vary with the kind of ore treated in the system; but iron reduced at 1400° F. from a good grade of many finely divided ores will not reoxidize if below about 500° F. when exposed to air. Further cooling of the reduced ore may be accomplished by using a water cooling coil in the system.

Certain ores when reduced are also readily separated from non-magnetic impurities by magnetic means; and a magnetic separator is indicated at 28. The magnetic separation may be carried on in air providing the reduced materials are below the reoxidation temperature. Otherwise the magnetic separator will be located in a protective atmosphere. The tailings from the reduced material are, of course, taken out of the system at 29, and the finely divided reduced material may be delivered by means 30 to a briquetting press 31. For most uses the briquettes will be melted in a suitable furnace such as an electric-arc furnace (not shown). From good quality ores in the way described, it is readily possible to make a product containing 94% iron with a silica content of less than 3%. For reduced materials which do not respond well to magnetic separation, apparatus element 28 may be omitted.

The cooled gases leave the ore cooler or separator at the point marked 32, whence they are delivered by conduits, not shown, to a second gas cleaning system, not shown, and then to the various places in the system at which fuel is required. Thus the fuel introduced into the steam-methane reformer 2 at the point 3, the fuel used in the preheat furnace 8 at 9, the fuel used in the drying kiln 12 and the fuel introduced into the ore preheater 18 at 20 can all be supplied from the tail gases derived from the device 26 at 32. It has been found that the fuel requirements of the system are such as to use up all of the tail gases available at 32. Since the combustion of the fuel in the steam-methane reformer, the gas preheat furnace, the drying kiln and the ore preheater is complete in each instance, the system fully employs in useful operations all of the combustible values of the tail gases, and does not produce tail gases in excess which must be disposed of or used elsewhere.

The thermodynamic efficiency of the system is therefore very high, and is superior to that of systems heretofore devised. All of the operations described are useful in the making of the reduced product in the manner taught herein; but the system involves no substantial heat losses excepting at the two cooling devices 7 and 24.

The system is designed to handle any iron ore materials in finely divided form; but it does not constitute a departure from the spirit of the invention to mix certain substances with the ore being treated. Thus a flux such as limestone may be used with the finely divided iron ores. At the temperatures involved little trouble is had with sticking or sintering of the reduced materials in the reactor or elsewhere. The reduced products of some ores have a greater tendency toward sticking and sintering; and while a flux is not usually of much help in this regard, finely divided carbon or iron carbide mixed with the ore will prevent sticking and sintering. In the system of this invention it is possible to form finely divided carbon or iron carbide in the ore preheater or in the reformer by controlling the combustion of the tail gas or by introducing and cracking a hydrocarbon providing the conditions there are not so strongly oxidizing as to destroy the carbon. However, since carbon can be released by the combination of two molecules of carbon monoxide to form carbon plus a molecule of carbon dioxide, and since this reaction is in part controlled by temperature, it is possible to release carbon within the reactor in a controlled fashion by varying the temperature and by introducing additional quantities of carbonaceous gases. A very small quantity of carbon is usually sufficient to prevent sticking and sintering, and no instances have been found where the quantity of carbon necessary was greater than about 8% of the iron, from 6% to 7% or less being a usual maximum.

If the quantity of fuel gas available at the point 32 is not sufficient for the purposes set forth above, it goes without saying that it may be supplemented by the addition of some other fuel without losing any of the advantages of the process.

Modifications may be made in the invention without departing from the spirit of it. The invention having been described in certain exemplary embodiments, what is claimed as new and desired to be secured by Letters Patent is:

1. A process for the fluidized-solids reduction of finely divided iron ores, the said process comprising the following steps:

(A) preheating finely divided iron ore in a preheating zone through the burning of a fuel with air to form products of combustion substantially devoid of reducing values,

(B) transferring the preheated finely divided iron ore to a reducing zone and fluidizing it in a reducing atmosphere while preventing the commingling of said products of combustion and said reducing atmosphere,

(C) transferring the said reducing atmosphere after use in the said reducing zone to a cooling zone, and there cooling and removing moisture from it,

(D) transferring the reduced ore product of step (B) to a cooling zone and there treating it with the cooled reducing atmosphere from step (C) so as to cool it to a temperature below the air oxidation temperature, while preventing the commingling of the atmospheres in steps (B), (C) and (D), and

(E) transferring at least a portion of the atmosphere from step (D) to the said preheating zone and burning it as the fuel in step (A), whereby to avoid the repeated passage of gases through the said process.

2. The process claimed in claim 1 including the further steps of:

(F) producing the reducing atmosphere for use in step (B) by the steam reformation of a gas whereby a gaseous mixture consisting principally of hydrogen and carbon monoxide is obtained,

(G) applying heat to said gas in admixture with steam during said reformation, by the combustion of a gaseous fuel,

(H) employing as said gaseous fuel a portion of the atmosphere derived from step (D),

(I) cooling the said reformed gaseous mixture to remove moisture therefrom,

(J) and thereafter reheating the said reformed gaseous mixture before transferring it to the said reducing zone for the performance of step (B).

3. The process claimed in claim 2, wherein the reheating of said reformed gaseous mixture in step (J) is accomplished through the burning of a gaseous fuel with air, the said gaseous fuel being derived in part at least from the atmosphere of step (D).

4. The process claimed in claim 3 including the further steps of:

(K) drying the finely divided ore prior to the preheating of step (A) by burning a gaseous fuel with air in a drying zone, and

(L) transferring at least a portion of the atmosphere from step (D) to the said drying zone and burning it with air therein to produce the heat required for drying, so that combustible values in the atmosphere from step (D) are used up in steps (A), (H), (J) and (K) in the formation of products of combustion substantially devoid of reducing values, whereby all combustible values in any gases produced in the process will be consumed therein.

5. In apparatus for the reduction of finely divided iron ore in a fluidized-solids reactor, by means of reducing gases passing through the reactor a single time only, the combination of a fuel fired ore preheater, a fluidizing reactor, means for delivering heated ore from the ore preheater to the reactor through a means for preventing commingling of the atmospheres of the reactor and the preheater, a gas cooler, means for delivering tail gases from the reactor to the gas cooler, an ore cooler, means for delivering reduced ore from the reactor to the ore cooler, means for delivering cooled tail gases from the gas cooler to the ore cooler wherein said cooled gases are commingled with the reduced ore whereby to cool it to a temperature below the reoxidation temperature, and means for delivering gases from the ore cooler to the ore preheater for combustion with air in the preheater.

6. Apparatus as claimed in claim 5 including means for delivering to said reactor reducing gases at a high temperature, said means comprising in the order named a steam methane reformer for converting gaseous fuel into a gaseous mixture containing relatively large quantities of carbon monoxide and hydrogen, a gas cooler for removing moisture from said gaseous mixture, and a preheating furnace for said gaseous mixture.

7. Apparatus as claimed in claim 6 including means for delivering gases from said ore cooler to said steam-methane reformer and said gas preheating furnace.

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