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(54) **IRON ORE REDUCTION METHOD AND INSTALLATION THEREFOR**

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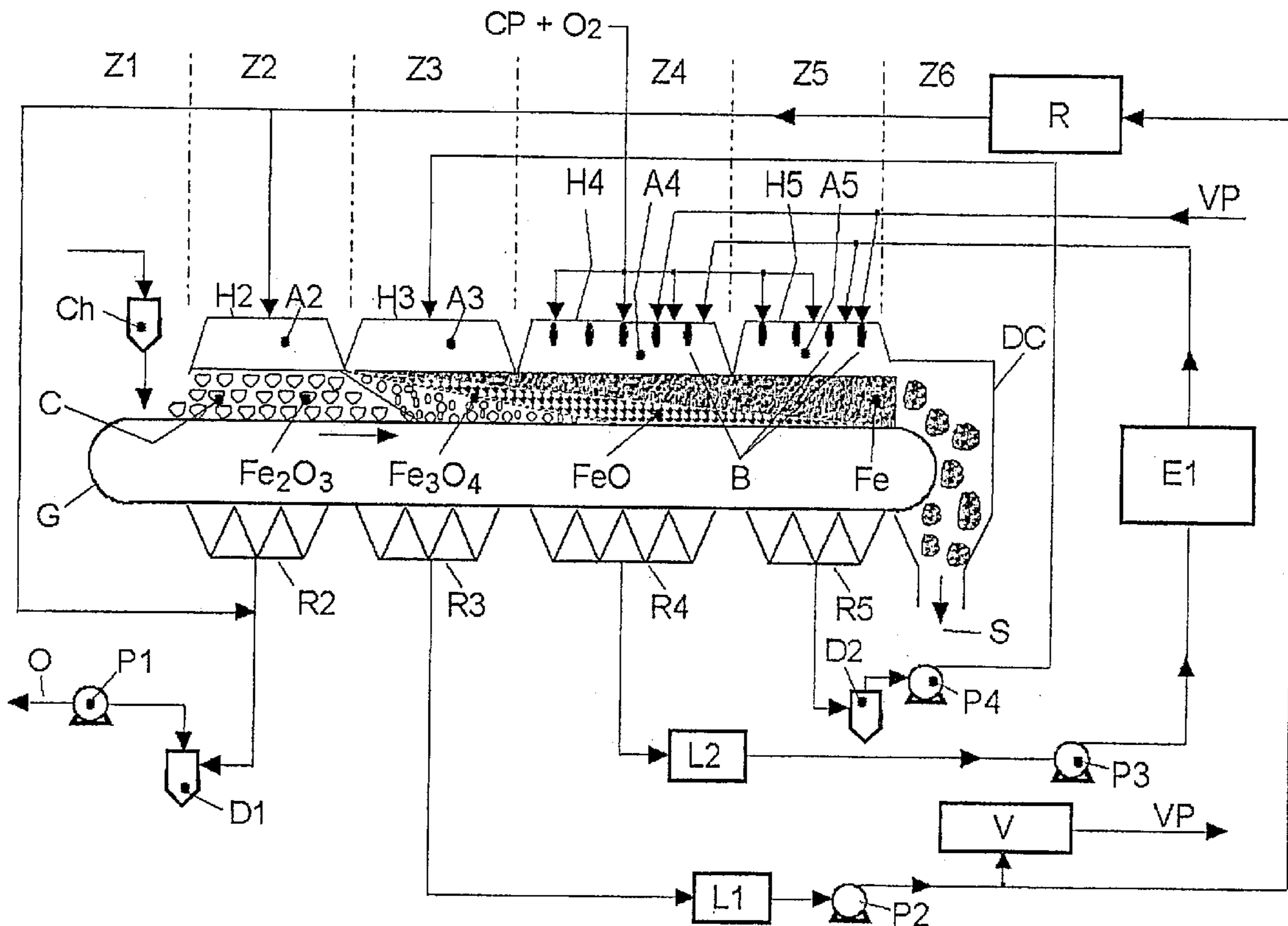
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(57) **ABSTRACT**

The invention concerns a method for iron reduction to make sponge iron which consists in: depositing a feed of iron ore on a grate and moving the grate so as to cause the feed to pass in at least three different zones; inputting gases, called input gases into one or several zones, including a hot gaseous carbonaceous reducing agent, and forcing said input gases through the ore located on the grate; and capturing the gases resulting from said forced passage, called output gases. The passage of the input gases brings the ore to a temperature ranging between 850° C. and 1300° C.; maintaining said feed at said temperature until an iron ore metallizing rate ranging between 60% and 100% is obtained. The feed deposited on the grate consists of either iron ore calibrated between 5 mm and 40 mm, or iron ore pellets having a diameter ranging between 5 mm and 20 mm, or iron ore granules of size between 2 mm and 10 mm, and the thickness of the deposited layer ranges between 150 mm and 600 mm. The flux of input gases, through the feed deposited on the grate, is directed from up downwards and generally obtained by generating beneath the grate an under-pressure ranging between 500 and 200 of water column. The forced flow of input gases through the feed in at least one processing zone consists at least partly of the output gas captured under the grate, said output gas captured under the grate having been at least subjected to a treatment such as scrubbing, desulphurization, drying, dust extraction, reheating and carbonate removal.



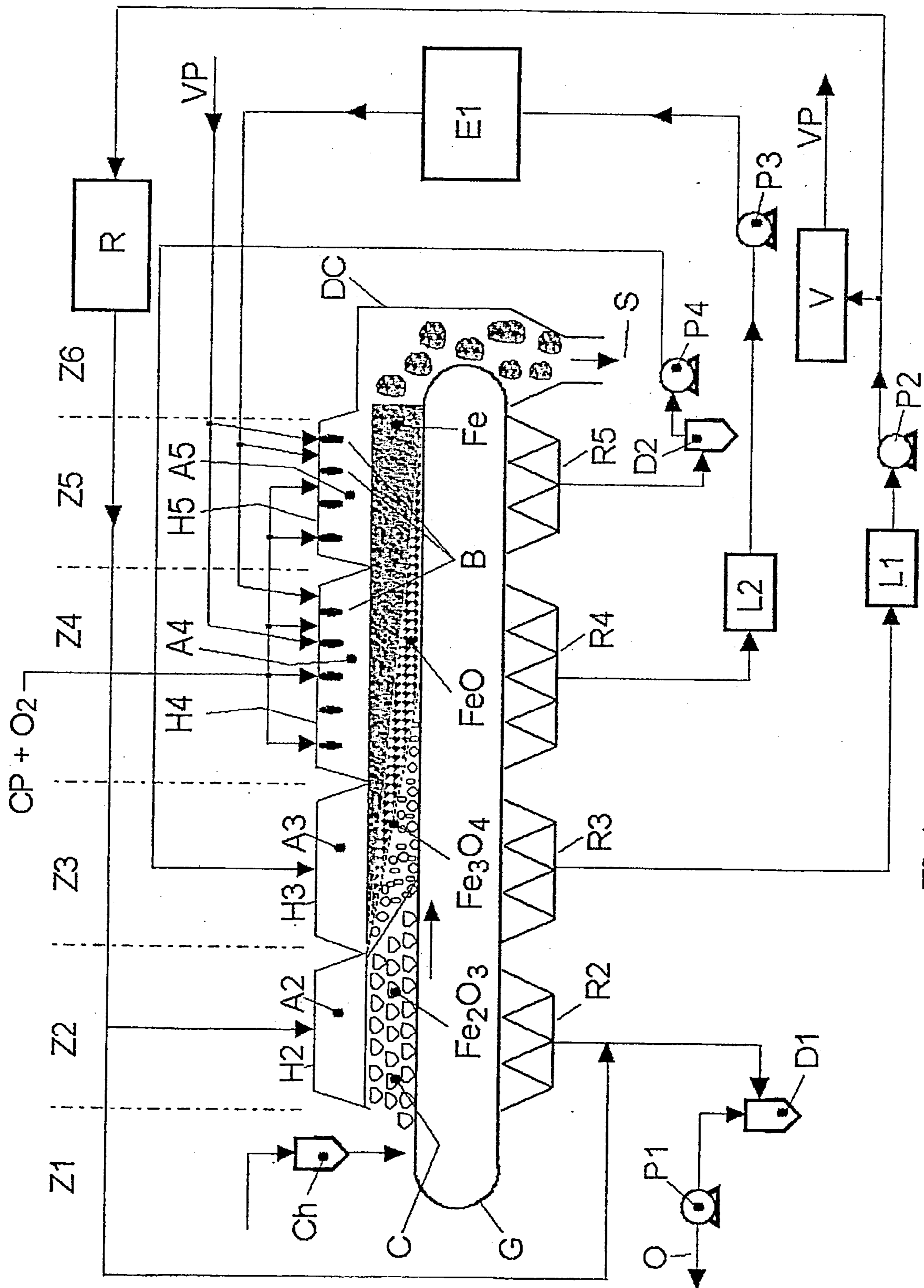


FIG. 1

### IRON ORE REDUCTION METHOD AND INSTALLATION THEREFOR

[0001] The present invention relates to a process for reducing iron ore and to an installation for implementing it.

[0002] In the sense of the present invention, iron sponge is a ferrous material obtained from iron oxide by a reduction operation referred to as direct reduction operation. Iron oxide is traditionally obtained from ores, in which it is accompanied by various undesirable substances forming the gangue. Currently, another interesting source of iron oxide is also formed by the surface oxides collected at various stages of steel-making processes, such as mill slivers and wash sludges. This category of oxides does not comprise gangue but often contains impurities, such as oil or grease residues.

[0003] The following description will refer to the general term "iron ore"; here, this term includes both the customary iron ores and oxides derived from steel-making processes, either separately or in the form of mixtures in any proportions.

[0004] Currently, iron sponge arouses growing interest, particularly as regards its use in converters, in alternative processes for the production of cast iron and in electric steelworks furnaces. Up until now, the metallic load of electric steelworks furnaces has been mainly made up of scrap iron. However, it has been observed that the quality of this scrap iron tends to decline, especially because of its content of alloying elements, which may be undesirable for the considered steels. Moreover, the price of scrap iron varies sometimes considerably depending not only on its quality but also on its availability, something that may compromise supplies to electric steel plants in particular. Hence the growing interest in the supply of "clean" iron through the addition of high-quality DRI or of cast iron produced by melting DRI of inferior quality.

[0005] Numerous direct reduction processes are known in the prior art. These processes are based on the use of a reducing agent, which is generally either gaseous or solid. The process of the invention belongs to the category of processes based on the use of a gaseous reducing agent, which is essentially a hot reducing gas, preferably produced from coal.

[0006] The known processes in this field are implemented in furnaces of various types, such as shaft furnaces, fluidised-bed furnaces or rotary furnaces, the productivity of which is low and which may require significant investment and entail high operating costs. A general tendency to seek an increase in yield while reducing energy costs per tonne of iron sponge produced is also observable.

[0007] Moreover, owing to the imposition of ever-stricter legal standards on industry, the treatment of waste in terms of its impact on the environment inevitably had to be taken into consideration and included within the framework of operating costs, said costs being ever higher to meet legal requirements.

[0008] The present invention relates to a process for manufacturing iron sponge based on the economically acceptable use of a gaseous carbonaceous reducing agent. Moreover, this process more easily fits the framework of respect for environmental norms thanks to the judicious use of the generated gaseous waste.

[0009] The extremely high productivity of the process of the present invention allows to reduce the impact of the investment pertaining to it when calculating the cost price of the iron sponge produced.

[0010] In accordance with the present invention, a process for reducing iron ores with a view to manufacturing iron sponge, in which a gaseous carbonaceous reducing agent is used, is characterised in that a load comprising iron ore is deposited on a grate, in that said grate is displaced in order to move said load into at least 3 separate treatment zones, the first zone comprising an operation for the formation of the load on the grate, the last comprising an operation for unloading the load comprising reduced iron ore from the grate, the intermediate zone or zones comprising, on the one hand, operations for supplying gaseous fluids, referred to as inlet gases, including a hot gaseous carbonaceous reducing agent, and forcing said gaseous flux through the load resting on the grate, and, on the other hand, operations for collecting the gaseous fluids, referred to as exit gases, resulting from said above-mentioned forced passage in such a way that said ore is raised to a temperature between 850° C. and 1300° C., preferably between 1050° C. and 1150° C., and in that said load is kept at this temperature until the metallisation rate of the iron ore present is between 60% and 100%, preferably between 85% and 95%.

[0011] The metallisation rate is the ratio of the percentage of metallic iron (Fe) to the total percentage of iron.

[0012] The notion of "grate" should be considered as an element for supporting the load of iron ore. Moreover, due to its construction, said grate can, on the one hand, be crossed by a gaseous flux and, on the other hand, serve to transfer the load through the different treatment zones.

[0013] According to a preferred embodiment of the process of the invention, the load deposited on the grate successively passes through at least one zone in which the temperature of the inlet gas is 450° C.±150° C., at least one zone in which the temperature of the inlet gas is 500° C.±150° C., at least one zone in which the temperature of the inlet gas is 1200° C.±150° C., and at least one zone in which the temperature of the inlet gas is 1000° C.±200° C.

[0014] The load deposited on the mobile grate comprises iron ore, which is preferably hematite that is partially hydrated and appropriately prepared for forming said load.

[0015] According to one embodiment of the process of the invention, the load deposited on the grate in the loading zone comprises ore mainly made up, in terms of volume, of iron ore sized between 5 mm and 40 mm, preferably between 5 mm and 10 mm.

[0016] Apart from the above-mentioned sized form, the iron ore can also be incorporated in the load deposited on the mobile grate in the form of pellets or granules, for example.

[0017] In general, both the pellets and the granules are obtained by a pelletising operation. However, the pellets have a relatively homogeneous structure in terms of volume, while the granules have an element that acts as a nucleus and serves as a tying base for finer particles.

[0018] According to another embodiment of the process of the invention, the load deposited on the grate in the loading zone comprises iron ore pellets with a diameter between 5 mm and 20 mm, preferably between 5 mm and 10 mm.

[0019] According to yet another embodiment of the process of the invention, the load deposited on the grate in the loading zone comprises iron ore granules with a size between 2 mm and 10 mm, preferably between 4 mm and 7 mm.

[0020] According to one embodiment of the process of the invention, a load formed by a layer with a thickness between 150 mm and 600 mm, preferably between 300 mm and 500 mm, is deposited on the grate.

[0021] According to one particular embodiment of the process of the invention, in the context of the presence of pellets or granules in the load deposited on the grate, a layer, referred to as a protection layer, is deposited on the grate and the load is deposited on said protection layer. The protection layer has a dual role, on the one hand, preventing the passage of the loaded materials through the grate and, on the other hand, avoiding adhesion of the materials making up the load in the case of partial melting of the materials. According to one embodiment of the process of the invention, the protection layer has a thickness between 30 mm and 100 mm, preferably between 40 and 60 mm.

[0022] According to a preferred embodiment of the process of the invention, the protection layer comprises at least one of the following elements: baked pellets, sized ore that may or may not have been pre-reduced or sized scrap iron, either alone or in combination with one or more of the above-mentioned elements.

[0023] According to a preferred embodiment of the process, which is the subject of the present invention, the protection layer made of constituents with a particle size between 5 mm and 40 mm, preferably between 10 mm and 15 mm.

[0024] An advantageous procedure for achieving the protection layer consists in using elements issued from what is referred to as "the upper particle size range" resulting from an grinding operation of at least part of the iron ore to be reduced. These elements are "larger" and serve as obstructions in the protection layer to prevent the elements of the load from falling through the mobile grate.

[0025] According to a preferred embodiment of the process, which is the subject of the present invention, a carbonaceous substance, preferably coal or coke dust, is incorporated into the load deposited on the mobile grate in a proportion between 1 kg and 40 kg of carbon present in said carbonaceous substance per ton of iron ore loaded before reduction.

[0026] This variant of the composition of the load allows to obtain satisfactory conditions for the reduction of said load of iron ore, i.e. with a metallisation rate at the unloading higher than 60%, even when gas fluxes forced through said load having a low reducing potential, owing for example to the presence of CO<sub>2</sub> and/or H<sub>2</sub>O, are used.

[0027] The above alternative embodiment of the load is of particular interest when using oxygen/coal burners that generate reducing gases containing CO<sub>2</sub> in proportions of 2% to 20% by volume of the gas issued from the burner.

[0028] After the loading of the grate, the latter serves as a means of transport for successively moving the load deposited within zones in which the conditions are controlled,

both with regard to temperature and with regard to the composition of the inlet gases passing through the load.

[0029] According to a preferred embodiment of the process of the invention, the flux of carbonaceous inlet gases through the load deposited on the grate is directed downwards, preferably by creating a vacuum between 500 and 2000 mm water column underneath the grate.

[0030] As the grate supporting the load progresses, the iron ore heats up on contact with the inlet gases, i.e. those that are drawn through the layer forming the load, and it is successively reduced into magnetite, wustite and finally metallic iron. Given that the aim is to achieve high reduction kinetics in the layer forming the load, said load needs to be raised to temperatures between 850° C. and 1300° C., preferably between 1050° C. and 1150° C.

[0031] According to one embodiment of the process of the invention, the flux of inlet gases forced through the load in at least one treatment zone is formed at least partially by exit gas collected underneath the grate, said collected gas has preferably undergone at least one treatment, such as a scrubbing, a desulphurisation, a drying, a dust-removal, a reheating or a decarbonation operation.

[0032] The above-mentioned treatments of scrubbing/drying and/or of decarbonation carried out on the exit gas are intended to restore the reducing potential of said gas before it is recycled towards a zone for treating the load on the grate.

[0033] In the case where the collected gas is not reheated before it is recycled towards a treatment zone in which it is forced through the load, it is advantageously mixed with gas issued from a coal gasification stage with a view to cooling the latter to a useful temperature for passing through the load, i.e. of the order of 1200° C.±150° C. or 1000° C.±200° C. The above-mentioned operation of mixing the gas with gas issued from a gasification stage allows to reduce or even omit the addition of the steam that is generally used as a cooling agent.

[0034] According to another preferred embodiment of the process of the invention, the flux of inlet gases forced through the load in a zone directly located after the loading zone is at least partially formed by fumes generated by the combustion of exit gas collected underneath the grate, said exit gas collected is preferably chosen among the exit gases collected with the lowest reducing potential, e.g. with a low CO content, said collected gas has advantageously undergone at least one scrubbing or dust-removal operation.

[0035] This way of proceeding has the economic advantage of recovering in situ the latent heat of said exit gases collected as a fuel for the production of the fumes used to preheat the load. An additional advantage is the fact that, after being used as a fuel, it can be unloaded via a flue, since the toxic elements have been neutralised during the combustion generating the above-mentioned fumes, the toxic CO has been transformed into non-toxic CO<sub>2</sub>, for example.

[0036] It is thus possible to preheat the load arranged on the grate either directly by means of gases emerging from the layer forming the load and collected downstream in the displacement direction of the grate relative to the preheating zone, either by means of the fumes produced by the com-

bustion of said above-mentioned exit gases or by means of the two above-mentioned instances in combination.

[0037] According to one embodiment of the process of the invention, hot reducing gas is produced from coal in a gasifier and said reducing gas obtained is used to form, at least in part, the gaseous carbonaceous reducing agent, which is forced to pass through the layer forming the load, which is deposited on the mobile grate, said gasifier being preferably supplied either with oxygen-enriched air or tonnage or pure oxygen.

[0038] The main advantage of using a gasifier in order to generate the reducing gas consists in that it is possible to produce a reduced iron or DRI of very high quality since it has a low content both of gangue and of sulphur. This result is linked with the possibility, both theoretically and physically, to eliminate directly at the level of the gasifier the ashes and sulphur from the coal used in said gasifier, these no longer being present in the DRI obtained on the mobile grate.

[0039] According to another embodiment of the process of the invention, a hot reducing gas is produced by means of one or more "oxygen/coal" burners in at least one zone for treating the load on the mobile grate, these preferably being zones in which the temperature of the inlet gas is higher than 800° C., said burners using either oxygenated air, pure oxygen or a mixture of the two, preferably supplied with pulverised coal, and said obtained reducing gas is used to form, at least in part, the gaseous carbonaceous reducing agent, which is forced through the layer forming the load, which is deposited on the mobile grate.

[0040] According to a preferred embodiment of the process of the invention, steam is used to control the temperature of the hot reducing gas produced in a gasifier or by "oxygen/coal" burners during the formation of the flux of gas forced through the load, the steam is preferably generated by a steam boiler, the fuel for which is formed, at least in part, by gases emerging from the layer forming the load and collected underneath the mobile grate, said collected exit gases preferably emerge from one or more zones in which the exit gases are too low in CO to be used as reducing gases, by being directly recycled for example, and too rich in CO<sub>2</sub> to be decarbonated at low cost, this typically being equivalent to  $20\% \leq \% \text{CO} < 40\%$  and  $35 \leq \% \text{CO}_2 < 55\%$  on dry gas.

[0041] Collecting at least part of the gases emerging from the layer deposited on the mobile grate and re-using it either as a mixture with the gaseous flux forced through said layer or as a fuel to generate steam or to generate hot fumes that can be used to preheat the load, on the one hand, allows to optimise the use of the reducing power and calorific value of said gases and, on the other hand, allows to minimise atmospheric emissions of pollutants such as CO.

[0042] According to one embodiment of the process of the invention, the vacuum created underneath the grate and/or the displacement speed of the mobile grate is/are modulated in such a way as to obtain a reduced ore with a metallisation rate between 60% and 100%, preferably between 85% and 95%, in the unloading zone.

[0043] The reduced ore is commonly called DRI.

[0044] According to a preferred embodiment of the process of the invention, the DRI obtained on the mobile grate

is directly unloaded towards a smelting furnace. The previous embodiment allows to optimise the use of the sensitive heat of the DRI in a significant way since, when it is unloaded, said DRI is at a temperature between 800° C. and 1200° C. Due to this, the operation of direct transfer towards a smelting furnace exerts a favourable influence on the energy balance of said smelting furnace.

[0045] The following description relates to a preferred embodiment of the process of the invention, in which the mobile grate successively passes through 6 zones, namely a loading zone, four zones for the treatment of the load with a view to reducing the iron ore, and one unloading zone, referred to as zones 1, 2, 3, 4, 5 and 6, respectively. In the text, reference will be made by means of letters and numbers to the sole attached figure, which is merely enclosed as a non-limitative illustration in the sense that some elements can exist within the context of the process that is the subject of the present invention without, however, being shown in the figure or can be shown in the figure without a reference in the text. Moreover, the different physical states of the iron ore to be reduced have been schematised and identified by the customary chemical formulae. As it passes along the grate, the ore changes from Fe<sub>2</sub>O<sub>3</sub> to Fe<sub>2</sub>O<sub>4</sub>, then to FeO and, finally, to Fe.

[0046] The functioning of the process is considered in the case of operations being underway, i.e. after a start-up phase during which the process is loaded and made to function until an operating state has been obtained in which the whole mobile grate is supporting a layer forming the load, both in the loading zone and in the unloading zone.

[0047] According to a particular embodiment of the process of the invention, in which a mobile grate (G) successively passes through a loading zone, four treatment zones, and one unloading zone, a layer comprising iron ore is deposited, preferably continuously and in a constant thickness, on the mobile grate (G) in the first zone (Z1), referred to as the loading zone, in order to form the load (C) to be reduced, the grate (G) is displaced, preferably continuously, so as to move the load (C) by means of the movement of the mobile grate (G) from the loading zone (Z1) to the unloading zone (Z6), successively passing through the treatment zones (Z2), (Z3), (Z4) and (Z5), the temperature of the gaseous flux forced to pass downwards through the load (C) deposited on the mobile grate (G) in zones (Z2) to (Z5) is regulated to 450° C. ± 150° C. in the case of zone (Z2), 500° C. ± 150° C. in the case of zone (Z3), 1200° C. ± 150° C. in the case of zone (Z4) and 1000° C. ± 200° C. in the case of zone (Z5) respectively, the gases emerging underneath the grate (G) from the layer are collected underneath the grate (G) in each of said zones (Z2) to (Z5), and at least part of the gases collected from at least one of the zones (Z2) to (Z5) is recycled towards means that control the gaseous fluxes forced through the load. In the above context, the load (C) is deposited on the mobile grate (G) and, after the loading phase, undergoes preheating without reduction in one zone, the rest of the heating is then combined with a reduction operation in the following 3 zones until an ore with a metallisation rate of at least 60% is obtained, this involving the recycling of the gases collected underneath the grate (G).

[0048] According to a preferred embodiment of the preceding mode, the following operations are carried out:

[0049] a gaseous flux comprising hot reducing gas formed from the gasification of coal into CO and H<sub>2</sub>,

preferably in a pulverised form, in the presence of oxygen and steam is forced through the load (C) arranged on the mobile grate (G) in zones (Z4) and (Z5);

[0050] at least part of the gas emerging underneath the grate (G) is collected in zone (Z3), it is subjected to a scrubbing operation, possibly also to a drying operation, and part is then directed towards a steam generator, in which the collected gas is used as fuel, and another part is directed towards a combustion chamber supplied with a significant excess of air and in which fumes are generated at a temperature of  $450^{\circ}\text{C} \pm 150^{\circ}\text{C}$ ., on the one hand, the fumes are introduced into zone (Z2), and, on the other hand, are mixed with exit gases collected in zone (Z2) to obtain a gas at a temperature that is above the acid dew point, the gas obtained being dedusted and then evacuated to the atmosphere via a flue;

[0051] at least part of the gas emerging underneath the grate in zone (Z4) is collected, it is subjected to a scrubbing operation and possibly a drying operation, and it is recycled, after decarbonation, towards zones (Z4) and (Z5) in order to form at least partly the gaseous flux forced through the layer forming the load (C) in these zones (Z4) and (Z5);

[0052] at least part of the gas emerging underneath the grate in zone (Z5) is collected, it is cooled, possibly by introducing water into it, it is dedusted and it is used in zone (Z3) to form the gaseous fluid forced through the layer forming the load in said zone (Z3).

[0053] The collection and recycling of exit gas in zone (Z4) has two significant advantages, said gas serves, on the one hand, to dilute the reducing gas produced by gasification of the coal and to control the temperature of the mixture obtained and, on the other hand, it reduces the consumption of coal by increasing the quantity of reducing gas available per unit weight of coal.

[0054] The sole attached FIGURE shows an installation for implementing the process of the present invention according to a preferred embodiment.

[0055] The installation for implementing the process according to the present invention, an illustration of which is given in the attached figure, comprises at least the following elements:

[0056] a grate (G), preferably formed by mobile carriages provided at their bottoms with elements, such as bars, that promote the passage of a gaseous flux, the grate being provided with means for displacing it in the direction of the arrow,

[0057] means (Ch) for depositing a material on the grate (G),

[0058] means for defining an atmosphere (A2), preferably a hood (H2),

[0059] means for defining an atmosphere (A3), preferably a hood (H3),

[0060] means for defining an atmosphere (A4), preferably a hood (H4),

[0061] means for defining an atmosphere (A5), preferably a hood (H5),

[0062] means (DC) for unloading the grate (G) and for transferring the load (C) towards an outlet (S),

[0063] dedusters (D1, D2) for treating a gaseous fluid and protecting the fans,

[0064] scrubbers (L1, L2) of gaseous fluids for removing dust and condensing part of the steam,

[0065] possibly dryers (not shown) for lowering and controlling the steam content,

[0066] means (E1, . . .) for decarbonating a gaseous fluid,

[0067] means (P1, P2, P3, P4) for propelling a gaseous fluid,

[0068] means (R2, R3, R4, R5) located underneath the mobile grate (G) to collect the gases emerging from the load (C) underneath said grate (G),

[0069] a combustion chamber (R),

[0070] a steam generator (V),

[0071] means for supplying (H2) gaseous fluid coming from the combustion chamber (R),

[0072] means for supplying (H3) gaseous fluid collected by (R5), which is dedusted in (D2) and compressed in (P4),

[0073] oxy-coal burners (B) mounted in (H4) and (H5),

[0074] means for introducing pulverised coal (CP), oxygen (O2) and steam (VP) from the steam generator (V) into (H4) and (H5) in order to produce reducing gas from pulverised coal, oxygen and steam,

[0075] means for supplying (H4) and (H5) with gaseous fluid that is recycled and collected in (R4), then passes into the scrubber (L2), possibly also a dryer, then into the compressor (P3) and finally into the decarbonator (E1),

[0076] means for guiding the exit gas collected in (R2), mixing it with fumes emerging from (R) and sending the resulting gas towards a deduster (D1), then towards a flue (O) via an extraction means (P1),

[0077] means for guiding the exit gas collected in (R3) so as to send it towards a scrubber (L1), possibly also a dryer, a compressor (P2) and then towards the steam generator (V) or the combustion chamber (R), where it is used as a fuel.

[0078] According to a preferred embodiment of the installation for implementing the process of the invention, oxy-coal burners (B) are vertically placed in the roof of the hood (H4) and (H5) of zones (Z4) and (Z5) on a number of lines parallel to one another and parallel to the displacement direction of the grate (G).

[0079] This arrangement allows the ashes produced by the combustion of the coal to settle in grooves, between which the ore forming the load remains "clean" and has better permeability to gases. In this way, a phenomenon of com-

plete or partial clogging of the layer forming the load on the grate by the ashes of the burnt coal is avoided, this phenomenon being highly damageable to the heating and reduction rate of the load (C).

[0080] The attached figure also allows to explain a process for implementing the process of the invention.

[0081] To simplify the explanation, the case of an installation in operation is examined, it focuses on the path of the exit gases collected underneath the mobile grate (G). Zones (Z4) and (Z5) are equipped with hoods (H4) and (H5), which are provided with oxy-coal burners supplied with pulverised coal, oxygen and steam so as to produce, as a mixture with recycled gas, a hot and highly reducing gas, i.e. at a temperature of 1200° C. in (H4) and 1000° C. in (H5), the flux of which is forced through the load deposited on the grate from the top downwards. After passing through the load on the grate, the hot reducing gas, which is rich in CO and H<sub>2</sub>, gives rise to an exit gas containing CO<sub>2</sub> and H<sub>2</sub>O derived from the CO and H<sub>2</sub>, following the reduction process of the iron ore. The exit gas collected in zone (Z4) underneath the grate is recycled in zones (Z4) and (Z5), after having undergone the scrubbing, condensation of the steam and finally decarbonation treatments. The decarbonation is achieved by absorption in a solvent such as methyl diethanolamine and, to this end, the exit gas is compressed at a pressure of around 5 bar absolute, then expanded after treatment, e.g. in a turbine on the same axis as the compressor so as to minimise the energy consumption for the compression by recovering the mechanical power generated during expansion in the turbine.

[0082] This gives a scrubbed and decarbonated gas which is highly reducing and which is reintroduced into zones (Z4) and (Z5), where it participates, as a mixture with the gases derived from the gasification of the coal, in the reduction of the iron ore.

[0083] As regards the exit gas collected underneath the grate in zone (Z5), it is generally at a temperature between 500° C. and 1000° C. and, if necessary, it is worthwhile to cool it, by injecting water for example, before proceeding to dust-removal in a multicyclone, and then to recycle it towards zone (Z3), where it acts as an initiator for the reduction of the iron ore layer forming the load by continuing the heating of the latter that has begun in zone (Z2). The exit gas collected underneath the grate in zone (Z3) is first of all scrubbed and dried, then used as a fuel, partly in the boiler for producing steam and partly in the combustion chamber. The fumes produced in the combustion chamber (R) are at a temperature of around 600° C. They are partly directed towards the hood (H2) to preheat the load deposited on the grate and partly towards the collecting means (R2), where they are mixed with relatively cool fumes ( $\pm 100^\circ$  C.) emerging underneath the grate so as to ensure that the resulting gaseous mixture is at a temperature higher than the acid dew point, e.g. 150° C., and as said mixture only contains O<sub>2</sub>, CO<sub>2</sub>, H<sub>2</sub>O and N<sub>2</sub>, i.e. in principle no toxic component, it can thus be unloaded into the atmosphere via a flue without special treatment, apart perhaps from a dust-removal.

[0084] It has been observed that implementation of the process of the invention is particularly advantageous when reducing ores sized within a particle size range from  $\pm 8$  mm to  $\pm 40$  mm, brought by moderate milling to a particle size

around the 5-10 mm fraction with a maximum size of 15 mm and the minimum possible fines of less than 5 mm. To recap, the ore ground so as to be 100% < 15 mm can advantageously be re-screened to 10 mm, for example, in such a way as to separate the 10-15 mm fraction and use it as a constituent of the protection layer that can be deposited on the mobile grate. The ore is preferentially iron ore based on partially hydrated hematite (combined water content of the order of 2% to 6%). The hematite is more suitable for processing than magnetite since it is more reducible, and the effect of the above-mentioned combined water content, after its loss during heating of the load to 600° C. on the grate, is to give rise to a large specific surface area and hence to promote high reactivity. However, an excessive combined water content has the disadvantage of producing excess crackling of the ore grains, an effect that is deleterious as regards the permeability of the layer and hence deleterious to the productivity of the reduction process. The vacuum applied underneath the grate in order to assist the passage of the gaseous fluid through the layer is typically of the order of 500 to 2000 mm water column. The hoods for guiding the gas into the different zones should operate under a constant relative pressure that is very slightly negative, of the order of -2 mm water column, in order to avoid any risk that CO or H<sub>2</sub> will escape into the working environment. Moreover, it is clear that any entry of parasitic air into the hoods should be avoided so as to avoid burning the reducing gas present there.

[0085] The DRI produced on the mobile grate is unloaded in zone (Z6) at a temperature of the order of 1000° C.

[0086] It will be noted that the implementation of the process of the invention allows the achievement of very high productivity, which is between 5 t to 20 t of DRI per m<sup>2</sup> of mobile grate and per day of operation.

[0087] In addition to the above remarks linked to the economic sector of the process of the invention, the following advantages will also be noted:

[0088] the ease both of loading and unloading the transport element, formed in this case by a mobile grate;

[0089] the thermal self-sufficiency, i.e. that the coal used in the process is sufficient both to generate the reducing gas required for the functioning of said reduction process and to supply the heat required both for the production of steam and the preheating of the ore;

[0090] the almost total absence or at least the presence in very small quantities of "spent gas"; the term "spent gas" is used to refer to a gas that has virtually exhausted its reducing potential and has a very low calorific value. Owing to these two elements, this gas is difficult to make use of and is even deleterious to the energy yield of the process if it has to be exported out of the latter, and this deleterious effect increases with the volumes of spent gas to be treated;

[0091] the possibility to use, for implementing the process of the invention, an existing agglomeration or pelletisation installation, both of them can be used for the DRI production process according to the invention while entailing only relatively low costs for the adaptation of the installations.

1. Process for the reduction of iron ore with a view to producing iron sponge, in which a gaseous carbonaceous reducing agent is used, characterised in that a load comprising iron ore is deposited on a grate, in that said grate is displaced in order to move said load into at least 3 separate treatment zones, in that the first zone comprises an operation for the formation of the load on the grate, in that the last comprises an operation of unloading the load comprising reduced iron ore from the grate, in that the intermediate zone or zones comprise operations involving the supply of gaseous fluids, referred to as inlet gases, including a hot gaseous carbonaceous reducing agent, in that said gaseous flux or inlet gases are forced through the load on the grate, in that the above-mentioned intermediate zones comprise operations of collecting the gaseous fluids, referred to as exit gases, resulting from said above-mentioned forced passage, in that said ore is raised in this way to a temperature between 850° C. and 1300° C., and in that said load is kept at this temperature until a metallisation rate of the iron ore present is between 60% and 100%.

2. Process according to claim 1, characterised in that said ore is raised to a temperature between 1050° C. and 1150° C.

3. Process according to claims 1 or 2, characterised in that said load is kept at the above-mentioned temperature until a metallisation rate of the iron ore present is between 85% and 95%.

4. Process according to any of claims 1 to 3, characterised in that the load deposited on the grate successively passes through at least one zone in which the temperature of the inlet gas is 450° C.±150° C., at least one zone in which the temperature of the inlet gas is 500° C.±150° C., at least one zone in which the temperature of the inlet gas is 1200° C.±150° C., and at least one zone in which the temperature of the inlet gas is 1000° C.±200° C.

5. Process according to one or more of claims 1 to 4, characterised in that the load deposited on the grate in the loading zone comprises ore mainly composed, in terms of volume, of iron ore sized between 5 mm and 40 mm.

6. Process according to claim 5, characterised in that the load deposited on the grate in the loading zone comprises ore mainly composed, in terms of volume, of iron ore sized between 5 and 10 mm.

7. Process according to one or more of claims 1 to 6, characterised in that the load deposited on the grate in the loading zone comprises iron ore pellets with a diameter between 5 mm and 20 mm.

8. Process according to claim 7, characterised in that the load deposited on the grate in the loading zone comprises iron ore pellets with a diameter between 5 mm and 10 mm.

9. Process according to one or more of claims 1 to 8, characterised in that the load deposited on the grate in the loading zone comprises iron ore granules with a size between 2 mm and 10 mm.

10. Process according to claim 9, characterised in that the load deposited on the grate in the loading zone comprises iron ore granules with a size between 4 mm and 7 mm.

11. Process according to one or more of claims 1 to 10, characterised in that a load formed by a layer with a thickness between 150 mm and 600 mm is deposited on the grate.

12. Process according to claim 11, characterised in that a load formed by a layer with a thickness between 300 mm and 500 mm is deposited on the grate.

13. Process according to any of claims 1 to 12, characterised in that a layer, referred to as a protection layer, is deposited on the grate, and in that the load is deposited on said protection layer.

14. Process according to claim 13, characterised in that the protection layer has a thickness between 30 mm and 100 mm.

15. Process according to claim 14, characterised in that the protection layer has a thickness between 40 mm and 60 mm.

16. Process according to one or more of claims 13 to 15, characterised in that the protection layer comprises at least one of the following elements: baked pellets, sized ore that may or may not have been pre-reduced or sized scrap iron, either alone or in combination with one or more of the above-mentioned elements.

17. Process according to one or more of claims 13 to 16, characterised in that the protection layer is made of constituents with a particle size between 5 mm and 40 mm.

18. Process according to claim 17, characterised in that the protection layer is made of constituents with a particle size between 10 mm and 15 mm.

19. Process according to one or more of claims 1 to 18, characterised in that a carbonaceous substance is incorporated into the load deposited on the mobile grate in a proportion between 1 kg and 40 kg of carbon present in said carbonaceous substance per ton of iron ore loaded before reduction.

20. Process according to claim 19, characterised in that the carbonaceous substance is coal.

21. Process according to claim 19, characterised in that the carbonaceous substance is coke dust.

22. Process according to one or more of claims 1 to 21, characterised in that the flux of carbonaceous inlet gases through the load deposited on the grate is directed downwards.

23. Process according to claim 22, characterised in that a vacuum between 500 and 2000 mm water column is created underneath the grate so as to obtain a downward flux of carbonaceous inlet gases through the load deposited on the grate.

24. Process according to one or more of claims 1 to 23, characterised in that the flux of inlet gases forced through the load in at least one treatment zone is formed at least partially by exit gas collected underneath the grate.

25. Process according to claim 24, characterised in that the exit gas collected underneath the grate has undergone at least one treatment, such as a scrubbing, a desulphurisation, a drying, a dust-removal, a reheating or a decarbonation operation.

26. Process according to one or more of claims 1 to 25, characterised in that the flux of inlet gases forced through the load in a zone directly located after the loading zone is formed at least partially by fumes generated by the combustion of exit gas collected underneath the grate.

27. Process according to claim 26, characterised in that the exit gas collected underneath the grate is chosen among the collected exit gases with the lowest reducing potential.

28. Process according to claim 26 or 27, characterised in that the exit gas collected underneath the grate has undergone at least one scrubbing or dust-removal operation.

29. Process according to any of claims 1 to 28, characterised in that hot reducing gas is produced from coal in a gasifier and in that said reducing gas obtained is used to form



at least partly the gaseous carbonaceous reducing agent, which is forced through the layer forming the load, which is deposited on the mobile grate.

**30.** Process according to claim 29, characterised in that the gasifier is supplied either with oxygen-enriched air or tonnage or pure oxygen.

**31.** Process according to any of claims 1 to 30, characterised in that a hot reducing gas is produced by means of one or more "oxygen/coal" burners in at least one zone for treating the load on the mobile grate, said burners using either oxygenated air, pure oxygen or a mixture of the two, and in that said reducing gas obtained is used to form at least partly the gaseous carbonaceous reducing agent, which is forced through the layer forming the load, which is deposited on the mobile grate.

**32.** Process according to claim 31, characterised in that the zone in which the reducing gas is produced is a zone in which the temperature of the inlet gas is higher than 800° C.

**33.** Process according to claim 31 or 32, characterised in that the burners are supplied with pulverised coal.

**34.** Process according to one or more of claims 29 to 33, characterised in that steam is used to control the temperature of the hot reducing-gas produced in a gasifier or by "oxygen/coal" burners during the formation of the flux of gas forced through the load.

**35.** Process according to claim 34, characterised in that the steam is generated by a steam boiler, the fuel for which is formed at least partly by gases emerging from the layer forming the load and collected underneath the mobile grate.

**36.** Process according to claim 35, characterised in that the exit gases collected emerge from one or more zones in which the exit gases are too low in CO to be used as reducing gases and too rich in CO<sub>2</sub> to be decarbonated at low cost.

**37.** Process according to claim 36, characterised in that the exit gases contain concentrations of CO and CO<sub>2</sub> in terms of volume on dry gas such that  $20\% \leq \% \text{CO} < 40\%$  and  $35 \leq \% \text{CO}_2 < 55\%$ .

**38.** Process according to one or more of claims 1 to 37, characterised in that the displacement speed of the mobile grate is modulated in such a way as to obtain a reduced ore with a metallisation rate between 60% and 100% in the unloading zone.

**39.** Process according to one or more of claims 1 to 37, characterised in that the vacuum created underneath the mobile grate is modulated in such a way as to obtain a reduced ore having a metallisation rate between 60% and 100% in the unloading zone.

**40.** Process according to one or more of claims 1 to 37, characterised in that the vacuum created underneath the mobile grate and the displacement speed of said grate are modulated in such a way as to obtain a reduced ore having a metallisation rate between 60% and 100% in the unloading zone.

**41.** Process according to one or more of claims 38 to 40, characterised in that the displacement speed of the mobile grate and/or the vacuum created underneath the mobile grate are modulated in such a way as to obtain a reduced ore having a metallisation rate between 85% and 95% in the unloading zone.

**42.** Process according to one or more of claims 1 to 41, characterised in that the DRI obtained on the mobile grate is directly unloaded towards a smelting furnace.

**43.** Process according to one or more of claims 1 to 42, in which a mobile grate (G) successively passes through a

loading zone, four treatment zones and one unloading zone, characterised in that, in the first zone (Z1), referred to as the loading zone, a layer comprising iron ore is deposited on the mobile grate (G) in order to form the load (C) to be reduced, in that the grate (G) is displaced so as to move the load (C), by means of the movement of the mobile grate (G), from the loading zone (Z1) to the unloading zone (Z6), successively passing through the treatment zones (Z2), (Z3), (Z4) and (Z5), in that the temperature of the gaseous flux forced downwards through the load (C) deposited on the mobile grate (G) in zones (Z2) to (Z5) is regulated to 450° C.±150° C. in the case of zone (Z2), 500° C.±150° C. in the case of zone (Z3), 1200° C.±150° C. in the case of zone (Z4) and 1000° C.±200° C. in the case of zone (Z5) respectively, in that the gases emerging underneath the grate (G) from the layer are collected underneath the grate (G) in each of said zones (Z2) to (Z5), and in that at least part of the gases collected from at least one of the zones (Z2) to (Z5) is recycled towards means that control the gaseous fluxes forced through the load.

**44.** Process according to claim 43, characterised in that a layer comprising iron ore is deposited continuously and in a constant thickness on the mobile grate (G) in the first zone (Z1), referred to as the loading zone, in order to form the load (C) to be reduced.

**45.** Process according to claim 43 or 44, characterised in that a gaseous flux comprising hot reducing gas formed from the gasification of coal into CO and H<sub>2</sub> in the presence of oxygen and steam is forced through the load (C) on the mobile grate (G) in zones (Z4) and (Z5), in that at least part of the gas emerging underneath the grate (G) is collected in zone (Z3), in that it is subjected to a scrubbing treatment, and in that part of it is then directed towards a steam generator, in which the collected gas is used as a fuel, and in that another part is directed towards a combustion chamber supplied with a significant excess of air, in which fumes are generated at a temperature of 450° C.±150° C., in that part of the fumes generated is introduced into zone (Z2), and in that another part of the fumes generated is mixed with exit gases collected in zone (Z2) to obtain a gas at a temperature above the acid dew point, in that the gas obtained is dedusted and then evacuated to atmosphere via a flue, in that at least part of the gas emerging underneath the grate in zone (Z4) is collected, in that it is subjected to scrubbing, and in that it is recycled towards zones (Z4) and (Z5) in order to form at least partly the gaseous flux forced through the layer forming the load (C) in these zones (Z4) and (Z5), in that at least part of the gas emerging underneath the grate in zone (Z5) is collected, in that it is cooled, in that it is dedusted and in that it is used in zone (Z3) to form the gaseous fluid forced through the layer forming the load in said zone (Z3).

**46.** Process according to claim 45, characterised in that the coal is in a pulverised form.

**47.** Process according to claim 45 or 46, characterised in that the exit gas collected underneath the grate (G) in zone (Z3) is subjected to a drying operation.

**48.** Process according to any of claims 45 to 47, characterised in that the exit gas collected underneath the grate (G) in zone (Z4) is subjected to decarbonation before it is recycled towards zones (Z4) and (Z5).

**49.** Process according to claim 45, characterised in that the exit gas collected underneath the grate (G) in zone (Z4) is subjected to a drying operation.

**50.** Process according to any of claims 45 to 49, characterised in that the exit gas collected underneath the grate in zone (Z5) is cooled by introducing water into it.

**51.** Installation for implementing the process of the present invention in accordance with one or more of claims 1 to 50, characterised in that it comprises at least:

a grate (G), preferably formed by mobile carriages provided with elements that promote the passage of a gaseous flux, the grate being provided with means for displacing it in the direction of the arrow,

means (Ch) for depositing a material on the grate (G),

means for defining an atmosphere (A2), preferably a hood (H2),

means for defining an atmosphere (A3), preferably a hood (H3),

means for defining an atmosphere (A4), preferably a hood (H4),

means for defining an atmosphere (A5), preferably a hood (H5),

means (DC) for unloading the grate (G) and for transferring the load (C) towards an outlet (S),

dedusters (D1, D2) for treating a gaseous fluid and protecting the fans,

scrubbers (L1, L2) of gaseous fluids for removing dust and condensing part of the steam,

possibly dryers (not shown) for lowering and controlling the steam content,

means (E1) for decarbonating a gaseous fluid,

means (P1, P2, P3, P4) for propelling a gaseous fluid,

means (R2, R3, R4, R5) located underneath the mobile grate (G) to collect the gases emerging from the load (C) underneath said grate (G),

a combustion chamber (R),

a steam generator (V),

means for supplying (H2) gaseous fluid coming from the combustion chamber (R),

means for supplying (H3) gaseous fluid collected by (R5), which is dedusted in (D2) and compressed in (P4),

oxy-coal burners (B) mounted in (H4) and (H5),

means for introducing pulverised coal (CP), oxygen (O2) and steam (VP) from the steam generator (V) into (H4) and (H5) in order to produce reducing gas from pulverised coal, oxygen and steam,

means for supplying (H4) and (H5) with gaseous fluid that is recycled and collected in (R4), then passes into the scrubber (L2), possibly also a dryer, then into the compressor (P3) and finally into the decarbonator (E1),

means for guiding the exit gas collected at (H2), mixing it with fumes emerging from (R) and sending the resulting gas towards a deduster (D1), then towards a flue (O) via the compressor (P1),

means for guiding the exit gas collected in (R3) so as to send it towards a scrubber (L1), possibly also a dryer, a compressor (P2) and then towards the steam generator (V) or the combustion chamber (R), where it is used as a fuel.

**52.** Installation according to claim 51, characterised in that oxy-coal burners (B) are vertically placed in the roof of the hood (H4) and (H5) of zones (Z4) and (Z5) on a number of lines parallel to one another and parallel to the displacement direction of the grate (G).

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