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(54) A METHOD FOR PRODUCING COLD DIRECT REDUCED IRON

(57) A method for producing direct reduced iron (DRI), comprising the steps of: controlling a flow rate of a non-heated hydrogen gas into a cooling section (5) such that Tdriout<Tdrioutmax, wherein Tdrimax is a set maximum allowable temperature of the DRI exiting the cooling section (5), measuring temperature of cooling gas Tcooltop leaving the cooling section and increasing the flow rate of the cooling gas, FRcoolgas, introduced into the cooling section (5) until Tcooltop=Tcooltopmin, adjusting a flow rate of a separately heated reduction gas introduced into a reduction section (4) and measuring the degree of metallization of the produced DRI and measuring the top gas temperature Ttopgas, and determining a minimum top gas temperature, Ttopgasmin, below which the degree of metallization is below a minimum allowable value, and measuring the top gas temperature Ttopgas and controlling at least one of the flow rate of the heated reducing gas and the temperature Tredgas to which the heated reducing gas is heated such that Ttopgasmin≤Ttopgas≤Topgasmax, wherein Topgasmax is a set maximum allowable temperature of the top gas.

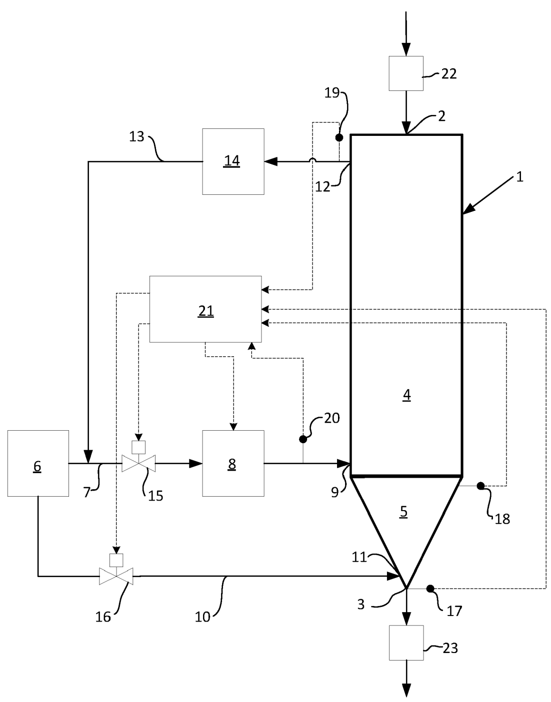

FIG. 1

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Description

TECHNICAL FIELD

[0001] The present invention relates to a method for producing direct reduced iron (DRI), the method comprising the steps of: a) introducing iron ore to an ore inlet of a direct reduction shaft; b) heating a reducing gas consisting essentially of hydrogen to a reduction gas temperature Tredgas and introducing the heated reducing gas into a reducing section of the direct reduction shaft to form a first component part of a reducing gas that reduces the iron ore to hot DRI at a reduction temperature Tred, wherein Tredgas>Tred; c) introducing a cooling gas consisting essentially of hydrogen and having a temperature Tcoolgas into a cooling section of the direct reduction shaft, said cooling section being located downstream the reducing section as seen in a flow direction of the DRI, wherein the cooling gas is introduced at an end of the cooling section opposite to the end of the cooling section which is adjacent to reduction section, and thereby cooling the hot DRI, which has a temperature Tdritop when entering the cooling section, to cold DRI and heating the cooling gas to a temperature Tcooltop (through heat exchange with the counterflowing DRI), wherein the cold DRI exiting the cooling section has a temperature Tdriout; d) permitting the hot cooling gas to enter the reducing section of the direct reduction shaft to mix with the heated reducing gas and form a second component part of the reducing gas; and e) removing a spent reducing gas as top gas from an upper part of the reducing section of the direct reduction shaft, said top gas having a temperature Ttopgas.

BACKGROUND

[0002] In connection to the reduction of iron oxide to iron by means of hydrogen gas, it has been suggested by prior art, e.g. in CN111926135A, to use hydrogen gas both as the reduction gas, which is heated and introduced into a reduction section of a reduction shaft, and as a cooling gas, which is introduced into a cooling section provided downstream the reduction section. The cooling gas is allowed to flow in an opposite direction to the flow direction of the direct reduction iron (DRI) passing through the cooling section, and is allowed to flow up into the reducing section, where it mixes with the externally heated reduction gas and contributes to the reduction process in the reducing section. Since the cooling gas has a substantially lower temperature than the DRI entering the cooling section from the reducing section, it will undergo a heat exchange with the DRI. Thereby, the process becomes more energy efficient.

[0003] However, CN111926135A is silent about how to optimise the flow rates of the cooling gas and the heated reducing gas respectively in order to achieve an even more energy efficient process, while still obtaining a product that fulfils certain quality criteria.

[0004] It is thus an object of the present invention to present a method as defined hereinabove and in the preamble of present patent claim 1 that improves the energy efficiency compared to prior art. In particular, the invention aims at reducing the energy consumption connected to the heating by external heaters of the reducing gas that is to be introduced directly into the reducing section (and not through the cooling section).

SUMMARY

[0005] The object of the invention is achieved by means of a method for producing direct reduced iron (DRI), the method comprising the steps of:

a) introducing iron ore to an ore inlet of a direct reduction shaft;

b) heating a reducing gas consisting essentially of hydrogen to a reduction gas temperature Tredgas and introducing the heated reducing gas into a reducing section of the direct reduction shaft to form a first component part of a reducing gas that reduces the iron ore to hot DRI at a reduction temperature Tred, wherein Tredgas>Tred;

c) introducing a cooling gas consisting essentially of hydrogen and having a temperature Tcoolgas into a cooling section of the direct reduction shaft, said cooling section being located downstream the reducing section as seen in a flow direction of the DRI, wherein the cooling gas is introduced at an end of the cooling section opposite to the end of the cooling section which is adjacent to reduction section, and thereby cooling the hot DRI, which has a temperature Tdritop when entering the cooling section, to cold DRI and heating the cooling gas to a temperature Tcooltop, wherein the cold DRI exiting the cooling section has a temperature Tdriout;

d) permitting the hot cooling gas to enter the reducing section of the direct reduction shaft to mix with the heated reducing gas and form a second component part of the reducing gas; and

e) removing a spent reducing gas as top gas from an upper part of the reducing section of the direct reduction shaft, said top gas having a temperature Ttopgas; said method being **characterized in that** it further comprises the steps of:

f) measuring Tdriout and controlling the flow rate of the cooling gas into the cooling section such that Tdriout<Tdrioutmax, wherein Tdrioutmax is a set maximum allowable temperature of the DRI exiting the cooling section,

g) measuring the temperature of the heated cooling gas Tcooltop and increasing the flow rate of the cooling gas, FRcoolgas, introduced into the cooling section until Tcooltop=Tcooltopmin, wherein Tcooltopmin is a predetermined lowest allowable temperature of the heated cooling gas and Tcooltopmin≤Tdritop,

h) adjusting a flow rate of the heated reduction gas, FRredgas, forming the first component part and determining the degree of metallization of the produced DRI and measuring the top gas temperature Ttopgas while doing so, and determining a minimum top gas temperature, Ttopgasmin, below which the degree of metallization is below a minimum allowable value,

i) measuring the top gas temperature Ttopgas and controlling at least one of the flow rate of the heated reduction gas, FRredgas, and the temperature Tredgas to which the heated reducing gas is heated before being introduced into the reducing section such that Ttopgasmin ≤Ttopgas≤Topgasmax, wherein Topgasmax is a set maximum allowable temperature of the top gas.

[0006] Step g) results in an optimisation of the heat exchange between cooling gas and DRI, and contributes to the enabling of a relatively lower flow rate of the externally heated reducing gas introduced into the reducing section, and thereby less energy consumption by the heater or heaters used for heating that first component part of the reducing gas.

[0007] Step h) may be achieved by adjusting the flow rate of the first component part, measuring the corresponding top gas temperature, and making laboratory measurements of the metallization degree of the DRI corresponding to different flow rate levels and top gas temperatures, and to decide at which top gas temperature that the metallization degree gets unacceptable from a product quality point of view.

[0008] Steps h) and i) prevents excessive total flow of reduction gas through the reduction shaft, and therefore also contributes to the lowering of the flow rate of the first component part of the reducing gas, and thus less energy consumption by heaters used for heating said first component part.

[0009] Tdritop may be determined by indirect temperature measurement. The peak temperature of Tcooltop, measured at low cooling gas flow rate, will be an indicator of Tdritop.

[0010] According to one embodiment, Ttopgasmax=Topgasmin+50°C.

[0011] According to one embodiment, Ttopgasmax=Topgasmin+25°C.

[0012] According to one embodiment, Ttopgasmax=Topgasmin.

[0013] According to one embodiment, Tcooltopmin=Tdritop-50°C.

[0014] According to one embodiment, Tcooltopmin=Tdritop-25°C.

[0015] According to one embodiment, Tcooltopmin=Tdritop-10°C.

[0016] According to one embodiment, Tcooltopmin=Tdritop.

[0017] According to one embodiment, the minimum allowable value of the degree of metallization is 90wt%, preferably 94wt%, even more preferably 96wt%, or even more preferably 98wt%.

[0018] According to one embodiment, 850°C < Tredgas < 1 200°C. According to another embodiment, 950°C < Tredgas < 1 100°C.

[0019] According to one embodiment, 900°C < Tred < 1 000°C.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] Embodiments of the invention will now be described in detail with regard to the annexed drawing, on which

Fig. 1 is schematic representation of parts of an arrangement for the direct reduction of iron ore to sponge iron, and

Fig. 2 is a flow chart showing an embodiment of a method according to the present invention.

DETAILED DESCRIPTION

[0021] With reference to fig. 1, an arrangement for direct reduction of iron ore to sponge iron is presented, on which arrangement a method according to the present invention may be applied.

[0022] The arrangement comprises a direct reduction shaft 1, having an inlet 2 for the introduction of iron ore into the shaft 1. At a bottom of the shaft 1 there is provided an outlet 3 for removal of sponge iron in the shape of pellets of direct reduced iron, DRI. The direct reduction shaft 1 comprises a reducing section 4, in which the reduction of the iron ore takes place, and a cooling section 5, which the DRI is cooled before exiting the shaft 1 through the outlet 3. The direct reduction shaft 1 is a vertical shaft, wherein the reducing section 4 is arranged on top of the cooling section 5 and wherein the inlet 2 for the introduction of iron ore is arranged at the top of the reducing section 4 and the outlet for removal of DRI is arranged at the bottom end of the cooling section 5. In other words, the cooling section 5 is located downstream the reducing section 4 as seen in a flow direction of the DRI. As a consequence of the design, and as will be disclosed later, cooling gas is introduced at an end of the cooling section 5 opposite to the end of the cooling section 5 which is adjacent to reduction section 4.

[0023] The arrangement further comprises a hydrogen gas source 6 comprising an electrolyser arranged to produce hydrogen gas from water. A first gas line 7 extends from the hydrogen gas source 6 to a heater arrangement 8, which, in a preferred embodiment comprises a plurality of electrical heaters. The first gas line 7 further extends from the heater arrangement 8 a reducing gas inlet 9, via which the hydrogen gas heated by the heater arrangement 8 and conducted through the first gas line 7 is introduced into the reducing section 4 of the reduction shaft 1.

[0024] A second gas line 10 extends from the hydrogen gas source 6 to a cooling gas inlet 11, through which non-heated hydrogen gas from the hydrogen gas source 6 is introduced into the cooling section 5 of the direct reduction shaft 1. The cooling gas inlet 11 is provided at the bottom of the cooling section 5.

[0025] At the top of the direct reduction shaft 1 there is provided a top gas outlet 12, through which reducing gas from the reduction shaft 1 is removed from the shaft 1. A third gas line 13 extends from the top gas outlet 12 to an arrangement 14 for top gas cleaning, including removal of water and dust from the top gas, such that, the cleaned top gas generally consists of hydrogen gas. The third gas line 13 further extends from the gas cleaning arrangement 14 and is connected to the first gas line 7 at a location upstream the heater arrangement 8. Thereby, non-spent hydrogen gas from the direct reduction shaft 1 can be recycled.

[0026] The arrangement for direct reduction of iron ore also comprises a first control valve 15 arranged in the first gas line 7 for the purpose of controlling the flow rate of the hydrogen gas that is to be heated in the heater arrangement 8 and introduced in the reducing section 4 via said heater arrangement 8. There is also provide a second control valve 16 arranged for the purpose of controlling the flow of hydrogen gas in the second gas line 10 from the hydrogen gas source to the cooling section 5.

[0027] The arrangement for direct reduction further comprises a first temperature sensor 17 configured to sense the temperature of the DRI exiting the cooling section 5. The first temperature sensor 17 is provided at the outlet 3 of the cooling section 5. There is also provided a second temperature sensor 18 configured to sense the temperature of the cooling gas Tcooltop at the top end of the cooling section 5. A third temperature sensor 19 is provided for the purpose of measuring the temperature of the top gas Ttopgas, and a fourth temperature sensor 20 is provided for the purpose of measuring the temperature Tredgas of the hydrogen gas heated by the heater arrangement.

[0028] The arrangement for direct reduction of iron ore further comprises a control unit 21 configured to control the operation of the heater arrangement 8, the first control valve 15 and the second control valve 16 on basis of input from the first, second, third and fourth temperature sensors 17-20.

[0029] The arrangement for direct reduction also comprises such components as compressors (not shown) for generating suitable gas pressures in the respective gas lines, wherein the process pressure in the direct reduction shaft may typically be in the region of 8-12 bars. There is also provided a charge vessel 22 via which the iron ore is introduced into the reducing section 4, and a discharge vessel 23 via which the DRI is removed from the cooling section 5. The charge vessel 22 and the discharge vessel 23 may be pressurised with any suitable gas, such as nitrogen gas, at times when they are open towards the reduction section 4 and the cooling section 5 respectively, in order to prevent pressurised process gas (mostly hydrogen gas) in the reduction section 4 and cooling section 5 from leaking out to the atmosphere. According to one embodiment, the gas used for pressurising a least one of the charge vessel 22 and the discharge vessel 23, preferably both of them, mainly comprises hydrogen gas. Thereby, introduction of other gases than hydrogen, such as nitrogen gas, into the reducing section 4 and cooling section 5 may be prevented.

[0030] The arrangement for direct reduction is configured to operate in accordance with the following description of an embodiment of the method of the present invention. Reference is made to fig. 2. The method comprises the following steps:

a) Introducing iron ore to the iron ore inlet 2 of the direct reduction shaft 1.

b) heating a reducing gas consisting essentially of hydrogen to a reduction gas temperature Tredgas and introducing the heated reducing gas into the reducing section 4 of the direct reduction shaft 1 form a first component part of a reducing gas that reduces the iron ore to hot DRI at a reduction temperature Tred, wherein Tredgas>Tred. The reducing gas is initially taken from the hydrogen gas source 6 and, when the reduction has started, partly from the top gas cleaned in the cleaning arrangement 14 and conducted to the heater arrangement 8 via the third gas line 7 and the first gas line 7.

c) Introducing a cooling gas consisting essentially of hydrogen and having a temperature Tcoolgas into the cooling section 5 of the direct reduction shaft 1, via the second gas line 10 and the inlet 11. Thereby, due to the counter-flow of the DRI and the cooling gas through the cooling section 5, the hot DRI, which has a temperature Tdritop when entering the cooling section 5, is cooled to an exit temperature Tdriout, and the cooling gas is heated to a temperature Tcooltop, reached at the top of the cooling section 5, or at the bottom of the reducing section 4.

d) Permitting the hot cooling gas to enter the reducing section 4 of the direct reduction shaft 1 to mix with the heated reducing gas delivered via the first gas line 7 and form a second component part of the reducing gas.

e) Removing top gas from the upper part of the reducing section 4 of the direct reduction shaft 1 through the top gas outlet 12, said top gas having a temperature Ttopgas.

f) Measuring Tdriout by means of the first temperature sensor 17 and controlling the flow rate of the cooling gas, FRcoolgas, into the cooling section 4 by means of the control unit 21 and the second control valve 16, such that Tdriout<Tdrioutmax, wherein Tdrioutmax is a set maximum allowable temperature

of the DRI exiting the cooling section 5.

g) Measuring the temperature of the heated cooling gas Tcooltop by means of the second temperature sensor 18 and increasing/adjusting the flow rate of the cooling gas introduced into the cooling section until Tcooltop=Tcooltopmin, wherein Tcooltopmin is a predetermined lowest allowable temperature of the heated cooling gas and Tcooltopmin≤Tdritop. The control unit 21 thereby controls the second control valve 16 on basis of the input from the second temperature sensor 18.

h) Adjusting a flow rate of the heated reduction gas, FRredgas, forming the first component part and determining the degree of metallization of the produced DRI and measuring the top gas temperature Ttopgas by means of the third temperature sensor while doing so, and determining a minimum top gas temperature, Ttopgasmin, below which the degree of metallization is below a minimum allowable value. The measuring of the degree of metallisation is, for the time being, done in laboratory, meaning that step h) may be regarded as an important step for determining a specific limit, and that once step h) has been used for determining that limit, minimisation of the energy consumption by the heater arrangement is mainly done through steps f), g) and i).

i) Measuring the top gas temperature Ttopgas and controlling at least one of the flow rate of the heated reducing gas, FRredgas, and the temperature Tredgas to which the heated reducing gas is heated before being introduced into the reducing section such that Ttopgasmin ≤Ttopgas≤Topgasmax, wherein Topgasmax is a set maximum allowable temperature of the top gas. The control unit 21 controls the first control valve 16 and the power of the heater arrangement for this purpose.

[0031] In the embodiment disclosed here, Ttopgasmax=Topgasmin, which means that the lowest possible top gas temperature, while still achieving satisfying metallization, is aimed at.

[0032] In the embodiment disclosed here, Tcooltopmin=Tdritop, which means that the heat of the DRI is optimally taken advantage of for the purpose of heating the cooling gas and thereby making it possible to reduce the energy consumption connected to the heating by heater arrangement 8 of the reducing gas that is to be introduced directly into the reducing section 4.

[0033] In the disclosed embodiment, Tdritop=Tred, as a result of the reducing section 4 and the cooling setion 5 being directly in connection to each other.

[0034] In one embodiment, Tredgas is approximately 1 050°C, and Tred is approximately 950°C.

[0035] In the disclosed embodiment, the minimum allowable value of the degree of metallization is 98wt%.

Claims

1. A method for producing direct reduced iron (DRI), the method comprising the steps of:

a) introducing iron ore to an iron ore inlet (2) of a direct reduction shaft (1);

b) heating a reducing gas consisting essentially of hydrogen to a reduction gas temperature Tredgas and introducing the heated reducing gas into a reducing section (4) of the direct reduction shaft to form a first component part of a reducing gas that reduces the iron ore to hot DRI at a reduction temperature Tred, wherein Tredgas>Tred;

c) introducing a cooling gas consisting essentially of hydrogen and having a temperature Tcoolgas into a cooling section (5) of the direct reduction shaft (1), said cooling section (5) being located downstream the reducing section (4) as seen in a flow direction of the DRI, wherein the cooling gas is introduced at an end of the cooling section (5) opposite to the end of the cooling section (5) which is adjacent to reducing section (4), and thereby cooling the hot DRI, which has a temperature Tdritop when entering the cooling section (5), to cold DRI and heating the cooling gas to a temperature Tcooltop, wherein the cold DRI exiting the cooling section (5) has a temperature Tdriout;

d) permitting the hot cooling gas to enter the reducing section (4) of the direct reduction shaft (1) to mix with the heated reducing gas and form a second component part of the reducing gas; and

e) removing a spent reducing gas as top gas from an upper part of the reducing section (4) of the direct reduction shaft (1), said top gas having a temperature Ttopgas; said method being **characterized in that** it further comprises the steps of:

f) measuring Tdriout and controlling the flow rate of the cooling gas, FRcoolgas, into the cooling section (5) such that Tdriout<Tdrioutmax, wherein Tdrioutmax is a set maximum allowable temperature of the DRI exiting the cooling section (5),

g) measuring the temperature of the heated cooling gas Tcooltop and increasing the flow rate of the cooling gas, FRcoolgas, introduced into the cooling section (5) until Tcooltop=Tcooltopmin, wherein Tcooltopmin is a predetermined lowest allowable temperature of the heated cooling gas and Tcooltopmin≤Tdritop,

h) adjusting a flow rate of the heated reduction gas, FRredgas, forming the first component part and determining the degree of metallization of the produced DRI and measuring the top gas

temperature Ttopgas while doing so, and determining a minimum top gas temperature, Ttopgasmin, below which the degree of metallization is below a minimum allowable value,
i) measuring the top gas temperature Ttopgas and controlling at least one of the flow rate of the heated reducing gas and the temperature Tredgas to which the heated reducing gas is heated before being introduced into the reducing section such that Ttopgasmin≤Ttopgas≤Topgasmax, wherein Topgasmax is a set maximum allowable temperature of the top gas.

2. A method according to clam 1, wherein Ttopgasmax=Topgasmin+50°C.

3. A method according to clam 1 or 2, wherein Ttopgasmax=Topgasmin+25°C.

4. A method according to claim 1 or 2, wherein Ttopgasmax=Topgasmin.

5. A method according to any one of claims 1-4, wherein Tcooltopmin=Tdritop-50°C.

6. A method according to any one of claims 1-4, wherein Tcooltopmin=Tdritop-25°C.

7. A method according to any one of claims 1-4, wherein Tcooltopmin=Tdritop-10°C.

8. A method according to any one of claims 1-4, wherein Tcooltopmin=Tdritop.

9. A method according to any one of the preceding claims, wherein Tdritop=Tred.

10. A method according to any one of the preceding claims, wherein the minimum allowable value of the degree of metallization is 90wt%, preferably 94wt%, even more preferably 96wt%, or even more preferably 98wt%.

11. A method according to any one of the preceding claims, wherein 850°C < Tredgas < 1 200°C.

12. A method according to any one of the preceding claims, wherein 900°C < Tred < 1 000°C.

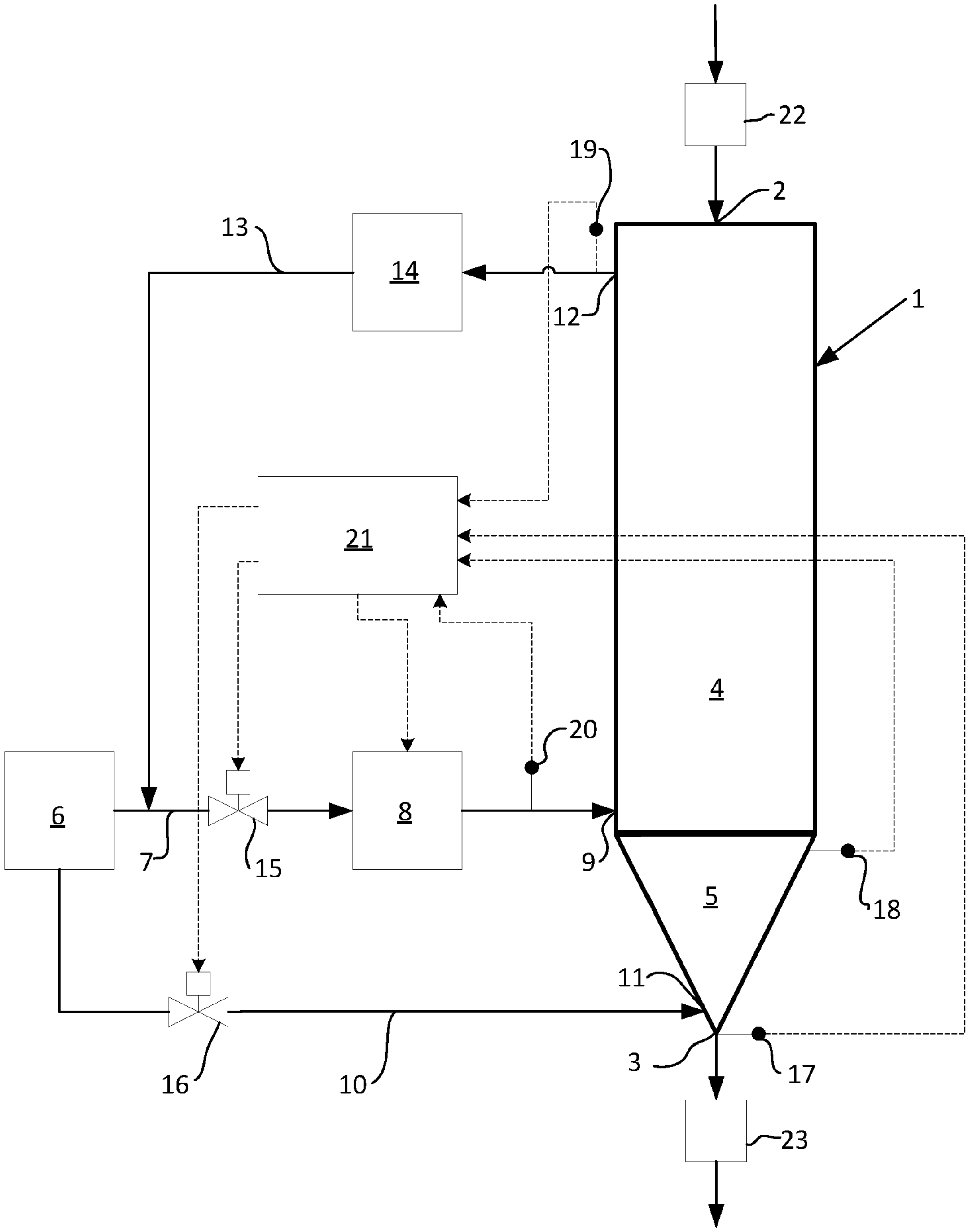

FIG. 1

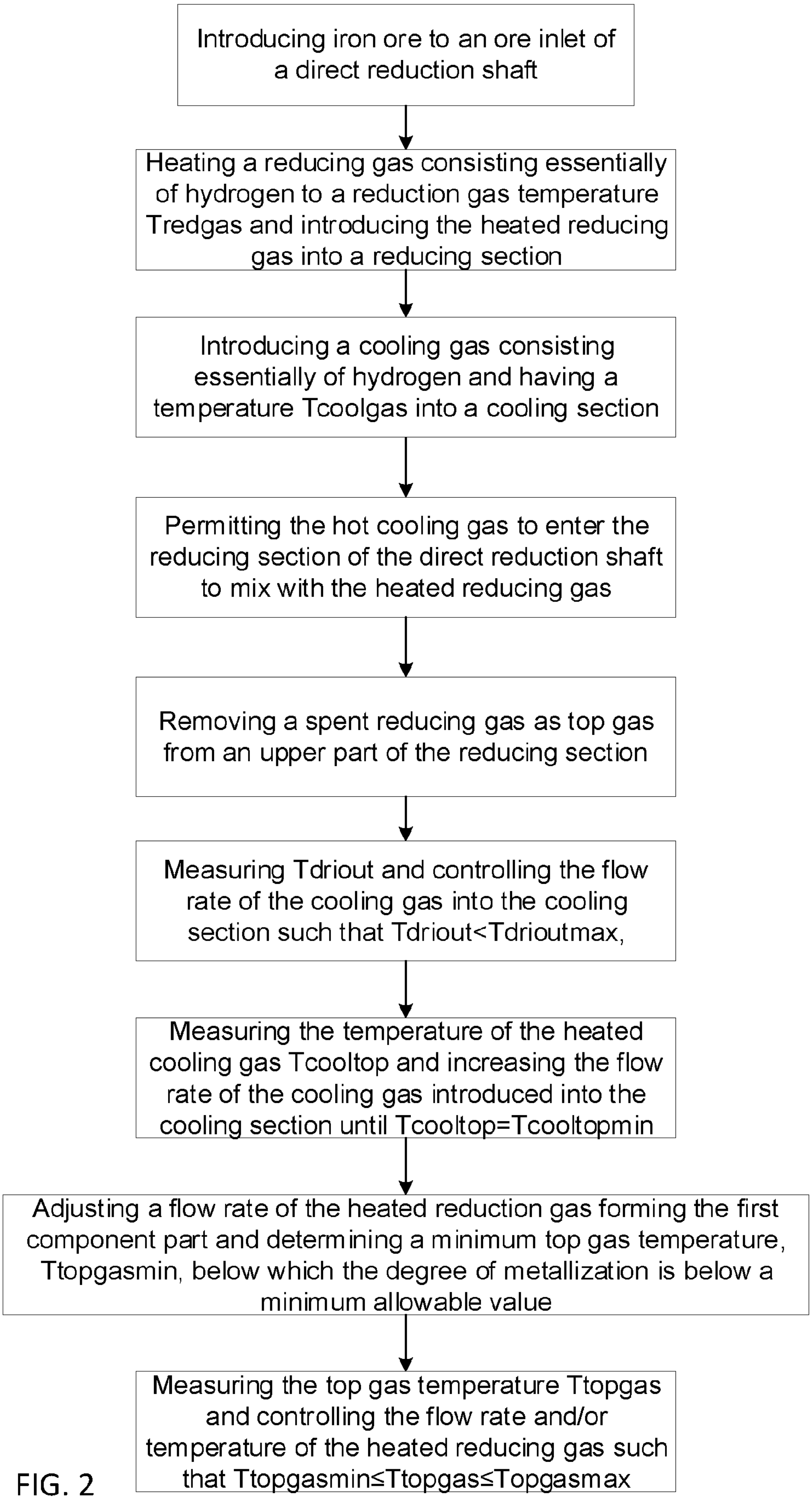
Introducing iron ore to an ore inlet of a direct reduction shaft
Heating a reducing gas consisting essentially of hydrogen to a reduction gas temperature Tredgas and introducing the heated reducing gas into a reducing section
Introducing a cooling gas consisting essentially of hydrogen and having a temperature Tcoolgas into a cooling section
Permitting the hot cooling gas to enter the reducing section of the direct reduction shaft to mix with the heated reducing gas
Removing a spent reducing gas as top gas from an upper part of the reducing section
Measuring Tdriout and controlling the flow rate of the cooling gas into the cooling section such that Tdriout<Tdrioutmax,
Measuring the temperature of the heated cooling gas Tcooltop and increasing the flow rate of the cooling gas introduced into the cooling section until Tcooltop=Tcooltopmin
Adjusting a flow rate of the heated reduction gas forming the first component part and determining a minimum top gas temperature, Ttopgasmin, below which the degree of metallization is below a minimum allowable value
Measuring the top gas temperature Ttopgas and controlling the flow rate and/or temperature of the heated reducing gas such that Ttopgasmin≤Ttopgas≤Topgasmax

FIG. 2

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EUROPEAN SEARCH REPORT

Application Number
EP 22 19 9172

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The present search report has been drawn up for all claims

2

Place of search	Date of completion of the search	Examiner
The Hague	27 February 2023	Vermeulen, Yves

CATEGORY OF CITED DOCUMENTS

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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 22 19 9172

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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