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Operating method of a network of plants

[001] The invention is related to a method to operate a network of plants and to the associated network of plants.

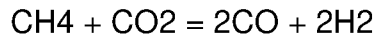
[002] Steel can be currently produced through two mains manufacturing routes. Nowadays, most commonly used production route consists in producing pig iron in a blast furnace, by use of a reducing agent, mainly coke, to reduce iron oxides. In this method, approx. 450 to 600 kg of coke, is consumed per metric ton of pig iron; this method, both in the production of coke from coal in a coking plant and in the production of the pig iron, releases significant quantities of CO₂.

[003] The second main route involves so-called "direct reduction methods". Among them are methods according to the brands MIDREX, FINMET, ENERGIRON/HYL, COREX, FINEX etc., in which sponge iron is produced in the form of HDRI (hot direct reduced iron), CDRI (cold direct reduced iron), or HBI (hot briquetted iron) from the direct reduction of iron oxide carriers. Sponge iron in the form of HDRI, CDRI, and HBI usually undergo further processing in electric arc furnaces.

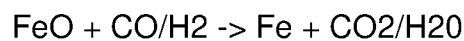
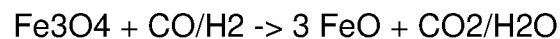
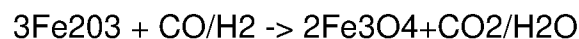
[004] There are three zones in each direct reduction shaft with cold DRI discharge: Reduction zone at top, transition zone at the middle, cooling zone at the cone shape bottom. In hot discharge DRI, this bottom part is used mainly for product homogenization before discharge, and control of overall solids follow.

[005] Reduction of the iron oxides occurs in the upper section of the furnace, at temperatures up to 950°C. Iron oxide ores and pellets containing around 30% by weight of Oxygen are charged to the top of a direct reduction shaft and are allowed to descend, by gravity, through a reducing gas. This reducing gas is entering the furnace from the bottom of reduction zone and flows counter-current from the charged oxidised iron. Oxygen contained in ores and pellets is removed in stepwise reduction of iron oxides in counter-current reaction between gases and oxide. Oxidant content of gas is increasing while gas is moving to the top of the furnace.

[006] The reducing gas generally comprises hydrogen and carbon monoxide (syngas) and is obtained by the catalytic reforming of natural gas. For example, in the so-called MIDREX method, first methane is transformed in a reformer according to the following reaction to produce the syngas or reduction gas:

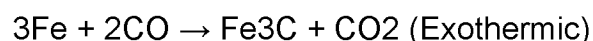
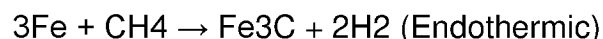


and the iron oxide reacts with the reduction gas, for example according to the following reactions:



At the end of the reduction zone the ore is metallized.

[007] A transition section is found below the reduction section; this section is of sufficient length to separate the reduction section from the cooling section, allowing an independent control of both sections. In this section carburization of the metallized product happens. Carburization is the process of increasing the carbon content of the metallized product inside the reduction furnace through following reactions:



[008] Injection of natural gas in the transition zone is using sensible heat of the metallized product in the transition zone to promote hydrocarbon cracking and carbon deposition. Due to relatively low concentration of oxidants, transition zone natural gas is more likely to crack to H_2 and Carbon than reforming to H_2 and CO . Hydrocarbon cracking provides carbon for DRI carburization and, at the same time adds reductant (H_2) to the gas that increases the gas reducing potential.

[009] Reducing CO_2 emissions to meet climate targets is challenging as the currently dominating form of steelmaking, the blast furnace-basic oxygen furnace (BF-BOF) route is dependent on coal as a reductant and fuel. There are two options for reducing CO_2 emissions from steelmaking: to keep the BF-BOF route and

implement carbon capture and storage of CO₂ (CCS) technology, or to seek new low-emissions processes.

[0010] A first step towards CO₂ emissions reductions maybe then to switch from a BF-BOF route to a DRI route. As this represents big changes, both in terms of equipment, but also in terms of process, all blast furnaces will not be replaced at once by direct reduction equipment. There would thus be some plants where the different equipment will coexist.

[0011] There is thus a need for a method allowing to operate a combination of a BF-BOF and DRI routes with the best efficiency, in terms of emission reduction but also energy efficiency and productivity.

[0012] This problem is solved by a method according to the invention, said method allowing to operate a network of plants comprising a blast furnace producing hot metal and a blast furnace gas, a steelmaking furnace producing steel and a steelmaking gas, a direct reduction furnace wherein oxidized iron is charged to be reduced by a reducing gas to produce direct reduced iron and a top reduction gas, at least one burner able to provide heat to the reducing gas before its injection into the direct reduction furnace, wherein the blast furnace gas and/or the steelmaking gas are used as fuel for said burner.

[0013] The method of the invention may also comprise the following optional characteristics considered separately or according to all possible technical combinations:

- the top reduction gas is captured and split into two streams, the first stream being recycled in the direct reduction furnace as reducing gas, the second stream being transformed into a syngas,
- the first stream represents from 40 to 99% in volume of the reduction top gas, preferably between 50 and 70% in volume,
- the network of plants further comprises a chemical and/or biochemical plant wherein said syngas is transformed into a chemical and/or a biochemical product,
- the first stream of top reduction gas is mixed with hydrogen gas to form the reducing gas before being heated,

- the network of plants further comprises an hydrogen production plant for the production of the hydrogen to be mixed with the reducing gas,
 - the hydrogen production plant is an electrolysis plant,
 - the heated reducing gas is mixed with carbon-carrying gas before injection
- 5 into the direct reduction furnace,
- the network of plants further comprises a coke oven producing coke and a coke oven gas, the carbon-carrying gas being a part of said coke oven gas.

[0014] The invention is also related to a comprising a blast furnace producing hot metal and a blast furnace gas, a steelmaking furnace producing steel and a

10 steelmaking gas, a direct reduction furnace wherein oxidized iron is charged to be reduced by a reducing gas to produce direct reduced iron and a top reduction gas, at least one burner able to provide heat to the reducing gas before its injection into the direct reduction, a gas line able to supply the blast furnace gas and/or steelmaking furnace gas as fuel to the burner.

15 [0015] Other characteristics and advantages of the invention will emerge clearly from the description of it that is given below by way of an indication and which is in no way restrictive, with reference to the appended figures in which:

- Figure 1 illustrates a network of plant to which a method according to the invention may be applied

20 Elements in the figures are illustration and may not have been drawn to scale.

[0016] Figure 1 illustrates a network of plants to which a method according to the invention may be applied. This network of plants comprises a direct reduction – or shaft – furnace 1, a blast furnace 2, a basic oxygen furnace 3. It may also optionally comprise a coke plant 4 and a plant 9 to produce hydrogen, such as an electrolysis

25 plant.

[0017] The direct reduction furnace 1 is charged at its top with oxidized iron 10 in form of ore or pellets. Said oxidized iron 10 is reduced into the furnace 1 by a reducing gas 11 injected into the furnace and flowing counter-current from oxidized iron. Reduced iron 12 exits the bottom of the furnace 1 for further processing, such

30 as briquetting before being used in subsequent steelmaking steps. Reducing gas

11 after having reduced iron exits at the top of the furnace as a top reduction gas
20 (TRG).

[0018] A cooling gas 26 is captured out of the cooling zone, subjected to a cleaning
step into a cleaning device 30, such as a scrubber, compressed in a compressor 31
5 and then sent back to the cooling zone of the shaft 1.

[0019] The blast furnace 2 produces hot metal, or pig iron and emits a blast furnace
gas (BFG) 41. The basic oxygen furnace 3, or more generally the steelmaking
furnace, produce steel out of hot metal and emits a steelmaking gas (BOFG) 42.
The coke oven plant 4 produces coke from coal and emits a coke oven gas (COG)
10 43.

[0020] Average composition of the different gases is summarized in table 1 –
compositions being expressed in %v:

	CO	CO ₂	H ₂	H ₂ O	CH ₄	N ₂
TRG	15-25	12-20	35-55	15-25	3-8	1-4
BFG	19-27	15-25	1-8	-	-	45-60
BOFG	55-65	14-16	3-5	-	0-1	14-16
COG	3-6	1-5	36-62	-	16-27	1-6

Table 1

[0021] The hydrogen production plant 9 produces a flux of hydrogen 40. It may be a
15 water or steam electrolysis plant. It is preferably operated using CO₂ neutral
electricity which includes notably electricity from renewable source which is defined
as energy that is collected from renewable resources, which are naturally
replenished on a human timescale, including sources like sunlight, wind, rain, tides,
waves, and geothermal heat. In some embodiments, the use of electricity coming
20 from nuclear sources can be used as it is not emitting CO₂ to be produced.

[0022] In the method according to the invention the reducing gas 11 is heated before being injected into the shaft furnace 1. Heat 25 necessary for this heating is provided by at least one burner 8, said burner 8 being operated with at least part of BOFG 42 and/or BFG 41 as fuel. The BFG and/or BOFG are first preferentially subjected to a cleaning step where they are quenched and cooled before reaching the burner 8.

[0023] Using BOFG and/or BFG as fuel allows to avoid using part of the reduction top gas 20, or hydrogen or natural gas as fuel to preheat reducing gas 11. This part of the top gas can be then further valorised. Burner may be of different kinds, for example, air burners, single regenerative burners, flameless oxy-fuel burners, double regenerative air-fuel, oxy-fuel and/or flat-flame burner. In a most preferred embodiment, the burner is supplied with exclusively BOF and/or BFG without any addition of natural gas or oxygen.

[0024] For example, in the embodiment of figure 1, the reduction top gas 20 after a dust and mist removal step in a cleaning device 5, such as a scrubber and a demister, is divided into two streams 21,22. A first stream, representing for example from 40 to 99%v, and preferably from 50 to 70%v, of the total top reduction gas, is sent to a preparation device 7 where it will be mixed with other gas, optionally reformed and heated to produce the reducing gas 11. In a preferred embodiment, the preparation device 7 is a reformer. The second stream 22 is sent to a separation unit 6 where said second stream 22 is split between a CO₂-rich gas 24 and a syngas (CO/H₂) 23. The CO₂-rich gas 21 may be either captured for storage or for further use in chemicals production. The syngas 23 may be sent to other plants such as chemical or biotechnological plant, such as a fermentation plant, to be valorised in form of chemical products, such as ethanol or methanol. Said separation may be performed using chemical absorption, adsorption or any other available technology.

[0025] The reducing gas 11 comprises the first stream 21 of reduction top gas to which is added pure hydrogen 40 produced by the hydrogen production plant 9. In another embodiment it may also comprise, in addition or in replacement of pure hydrogen, a quantity of natural gas.

[0026] Alternatively, to increase the carbon content of the Direct reduced Iron, an additional source of carbon can be added to the reduction gas. The network of plants may further comprise a coke plant 4 and COG 43 emitted from said coke plant may be injected into the shaft furnace 1 as carbon provider. In a preferred embodiment, COG is first split into a separation unit 36 between a H₂-rich gas 44 which can optionally be used as part of the reducing gas 11, and a carbon containing stream 45, rich in CH₄ and CO, which may be injected together with the reducing gas 11 and/or independently into the transition zone and/or with the cooling gas 26.

[0027] Such additional source of carbon can be in a gaseous form and/or in a solid form and can consist of biogas and/or of bio-coal.

[0028] A biogas is a renewable energy source that can be obtained by the breakdown of organic matter in the absence of oxygen inside a closed system called bioreactor. Biogas can be produced from raw materials such as agricultural waste, manure, municipal waste, plant material, sewage, green waste, food waste or any biodegradable materials.

[0029] A bio-coal is a carbon-neutral fuel that can replace fossil coal in industrial processes. It is produced by pyrolysis and carbonization of biomass performed within controlled temperature and residence time conditions. Thermal conversion of biomass, which is done under oxygen-free conditions process, allows to remove volatile organic compounds and cellulose components from the feedstock and create a solid biofuel with characteristics like the ones in fossil coal.

[0030] In a preferred embodiment, carbon content of the Direct Reduced Iron is set from 0.5 to 4 wt.%, preferably from 1 to 2 wt.% which allows getting a Direct Reduced Iron that can be easily handled and that keeps a good combustion potential for its future use.

[0031] The method according to the invention allows to have a better use of the reduction top gas in terms of valuable components valorisation while avoiding processing of BOFG and/or BFG. It allows thus to have an improved overall efficiency of the network of plants together with an optimised productivity and return

of investment. It moreover allows to reduce the carbon footprint of the global steelmaking production plant.

CLAIMS

1) A method of operating a network of plants comprising:

- a blast furnace producing hot metal and a blast furnace gas,
- 5 - a steelmaking furnace producing steel and a steelmaking gas,
- a direct reduction furnace wherein oxidized iron is charged to be reduced by a reducing gas to produce direct reduced iron and a top reduction gas,
- 10 - at least one burner able to provide heat to the reducing gas before its injection into the direct reduction furnace,

wherein the blast furnace gas and/or the steelmaking gas are used as fuel for said burner.

2) A method according to claim 1 wherein the top reduction gas is captured and split into two streams, the first stream being recycled in the direct reduction furnace as
15 reducing gas, the second stream being transformed into a syngas.

3) A method according to claim 2 wherein the first stream represents from 40 to 99% in volume of the reduction top gas.

4) A method according to claim 2 wherein the first stream represents from 50 to 70% in volume of the reduction top gas.

20 5) A method according to anyone of claims 2 to 4 wherein the network of plants further comprises a chemical and/or biochemical plant wherein said syngas is transformed into a chemical and/or a biochemical product.

6) A method according to anyone of the preceding claims wherein said first stream of top reduction gas is mixed with hydrogen gas to form the reducing gas before
25 being heated.

7) A method according to claim 6 wherein the network of plants further comprises an hydrogen production plant for the production of the hydrogen to be mixed with the reducing gas.

8) A method according to claim 74 wherein the hydrogen production plant is an electrolysis plant.

9) A method according to anyone of the previous claims wherein the heated reducing gas is mixed with carbon-carrying gas before injection into the direct reduction furnace.

10) A method according to claim 9 wherein the network of plants further comprises a coke oven producing coke and a coke oven gas, the carbon-carrying gas being a part of said coke oven gas.

11) A network of plants comprising:

- a. a blast furnace (2) producing hot metal and a blast furnace gas (41),
- b. a steelmaking furnace (3) producing steel and a steelmaking gas (42),
- c. a direct reduction furnace (1) wherein oxidized iron (10) is charged to be reduced by a reducing gas (11) to produce direct reduced iron (12) and a top reduction gas (20),
- d. at least one burner (8) able to provide heat (25) to the reducing gas (11) before its injection into the direct reduction,
- e. a gas line able to supply the blast furnace gas (41) and/or steelmaking furnace gas (42) as fuel to the burner (8).

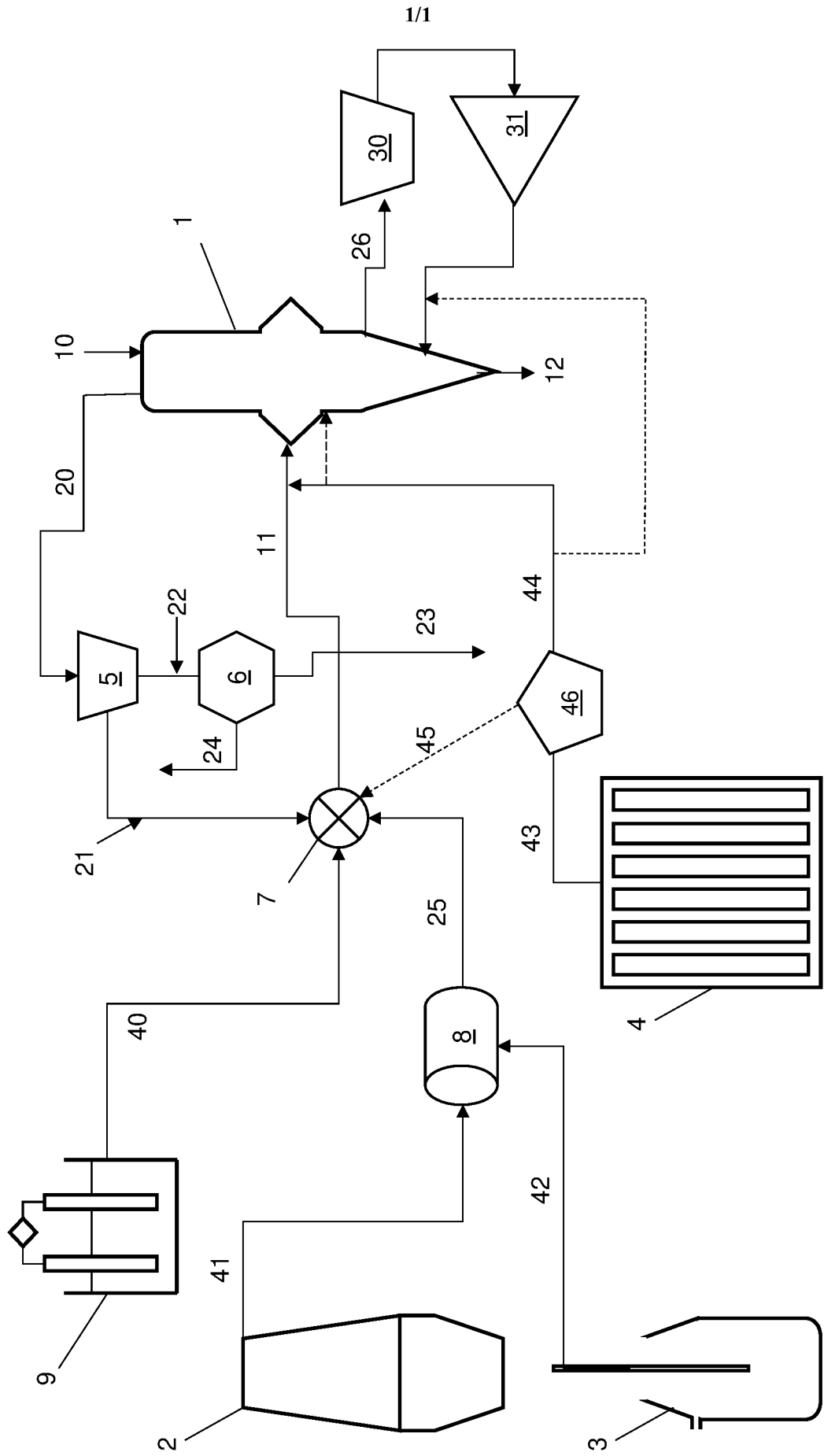


Figure 1

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2021/054243

A. CLASSIFICATION OF SUBJECT MATTER INV. C21B13/00 C21B7/00 C21C5/38 C21C5/28 ADD.		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) C21B C21C		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) EPO-Internal, WPI Data		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2004/101829 A2 (HYLSA SA [MX]) 25 November 2004 (2004-11-25) figure 1 table 1 page 10, line 7 - line 29	1-11
A	US 2016/348196 A1 (ACHATZ REINHOLD [DE] ET AL) 1 December 2016 (2016-12-01) paragraphs [0008], [0021]	2-5,8
☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 26 November 2021		Date of mailing of the international search report 08/12/2021
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Porté, Olivier

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2021/054243

Patent document cited in search report	Publication date	Patent family member(s)	Publication date	
WO 2004101829	A2	25-11-2004	BR PI0410313 A	23-05-2006
			CN 1791686 A	21-06-2006
			EP 1641945 A2	05-04-2006
			MX PA05012242 A	08-02-2006
			US 2004226406 A1	18-11-2004
			WO 2004101829 A2	25-11-2004

US 2016348196	A1	01-12-2016	AU 2014361206 A1	14-07-2016
			BR 112016011580 B1	01-12-2020
			CA 2930463 A1	18-06-2015
			CN 105980583 A	28-09-2016
			CN 113444849 A	28-09-2021
			DE 102013113933 A1	18-06-2015
			EP 3080307 A1	19-10-2016
			KR 20160097311 A	17-08-2016
			RU 2661688 C1	19-07-2018
			TW 201527512 A	16-07-2015
			UA 119339 C2	10-06-2019
			US 2016348196 A1	01-12-2016
			WO 2015086151 A1	18-06-2015
