

[Continued on next page]

Published:

— *with international search report (Art. 21(3))*

APPARATUS FOR THE PRODUCTION OF MOLTEN IRON

The invention relates to an apparatus for the production of molten iron comprising a metallurgical vessel, having a surrounding wall, a cyclone part provided on top of a smelt reduction part, the cyclone part being in open connection with the smelt reduction part and having at least one supply means around the circumference
5 of the surrounding wall adjusted to introduce oxygen gas into the cyclone part. The invention also relates to a method of producing molten iron in a metallurgical vessel.

Apparatuses for the production of molten iron are known in the art. EP 0726 326 A1 describes such an apparatus, which is also known as the Hlsarna process by Tata Steel. Supply means around the circumference of the surrounding wall adjusted to
10 introduce oxygen gas are known as well. For example EP 2794 931 B1 describes supply means adjusted for the introduction of oxygen gas into the cyclone part of the metallurgical vessel.

Unfortunately, this type of metallurgical vessel, having a cyclone part and a smelt reduction part, has the disadvantage that both parts cannot be controlled in an
15 independent manner. Especially the temperature control inside the metallurgical vessel is difficult, as both parts are in open connection with each other. This means that an adjustment in the smelt reduction part influences the cyclone part and vice versa.

The temperature control in the smelt reduction part is usually controlled by inserting a carbon containing material in the slag layer. However, the insertion does
20 not generate enough heat for the conversion from carbon, via carbon monoxide to carbon dioxide. The injection of oxygen gas in this part does generate enough energy, and therefore heat, as it converts the carbon monoxide to carbon dioxide. In order to keep the temperature within the processing window in the cyclone part, carbon containing material could be added in the smelt reduction part in the desired content.
25 However, this still can lead to a lower than desired temperature in the cyclone part and the current way to solve this is by the addition of even more oxygen gas in the smelt reduction vessel. This in turn will then lead to a temperature that may be too high in the smelt reduction part. The balance in temperature between the cyclone part and the smelt reduction part is therefore a delicate one and both parts are not controlled well
30 enough.

The inventors, being involved in finding more environmentally friendly solutions for molten iron production, found that this process could be controlled in a better way.

The object of this invention is to provide an apparatus and method that has a better control over the process. It is a further object to make better use of waste
35 materials and to produce less waste material during the ironmaking process, with an emphasis on lowering the emission of CO₂ per tonne of molten iron.

Accordingly, an apparatus and method for the production of molten iron is provided wherein the at least one supply means is further adjusted to introduce a mixture of oxygen gas and a combustible gas. This has the advantage that the temperature control of the process in the cyclone part is more independent from the temperature control of the smelt reduction part, since introducing the combustible gas together with the oxygen gas releases a lot of energy during the combustion process. The supply means is not particularly limited and may be a lance or an injector. By controlling the amount of combustible gas that is introduced, the energy, and therefore the heat that is released in the process can also be controlled.

Tests and simulations have proven that introducing the combustible gas and the oxygen gas with a predetermined mixture in the cyclone part of the metallurgical vessel can be done without any further adjustments. When the combustible gas is introduced, it will introduce more heat just below the cyclone part, leading to a higher temperature, especially in the cyclone part, but, at least partly, in the smelt reduction part as well. In this way it will lead to a better control over the cyclone part of the metallurgical vessel since the flow of both gases can be controlled and therefore a predetermined mixture can be introduced. Furthermore, the control of flow, and therefore temperature will be more independent from the smelt reduction part.

The combustible gas can be introduced in the cyclone part or at the top of the smelt reduction part, or a combination thereof. If the combustible gas is introduced at the top of the smelt reduction part, this will lead to a partial combustion of the gas and therefore a lower required quantity of coal.

Preferably the combustible gas is selected from the group of coke oven gas, converter gas, natural gas, hydrogen gas and liquefied petroleum gas. Coke oven gas contains +/- 3% carbon dioxide, +/- 6% carbon monoxide, 60-65% hydrogen, +/- 3% nitrogen and 25-30% methane. Converter gas roughly consists of 17-20% carbon dioxide, 60-65% carbon monoxide, +/- 1,5% hydrogen and 15-20% nitrogen. The main requirement is that the nitrogen content of the combustible gas should be relatively low, less than 20% (v/v). In this way any combustible gas having a low nitrogen content could be introduced. The control of the temperature will be at its best when the combustible gas is fully combusted during the process.

The inventors have found particularly good results with natural gas. Natural gas is predominantly methane (CH_4) and the amount thereof depends on the source. An advantage of the use of coke oven gas and converter gas is that they are at times considered to be waste material leading to undesired emissions. Therefore the use of these gases is a preferable option to combat climate change and reduce the amount of carbon dioxide in the atmosphere. The inventors feel the responsibility to act and do something, however small the steps may be, about climate change. They have the

desire to make the earth a more sustainable place for future generations and make climate activists happy, if at all possible.

If natural gas is used in a mixture containing 25% natural gas and 75% oxygen gas then an up to 2% reduction in CO₂ emissions was calculated by means of a simulation programme called IRMA (IRon MAKing) model. The IRMA programme uses a flow sheet design to break down the total process in building blocks. These building blocks are connected through material stream blocks. In this way a complex process can be divided in a number of simple steps. Calculations are based on a mix of thermodynamic equilibrium relations and empirical relations. Thermodynamic calculations are carried out by the ChemApp library, which also furnishes the library for the thermodynamic data. ChemApp is a product of GTTTechnologies and is based on the SimuSage package. The empirical theory is based on the "Cyclone-converter heat and mass balance model" developed at Tata Steel (Corus). Most of the building blocks are validated using other model results or literature.

A further advantage of using natural gas is that methane will be converted under the processing conditions into carbon dioxide and water. As is commonly known, methane is also a greenhouse gas and has an even bigger greenhouse effect than carbon dioxide. In general, the addition of a combustible gas, like natural gas, leads to a reduced use of coal. And therefore also less carbon dioxide will be formed during the process, bringing the environmental benefits that the inventors are after.

Preferably, the supply means are symmetrically distributed over the circumference of the surrounding wall of the cyclone part or at the top of the smelt reduction unit. This is beneficial for a good gas distribution within the cyclone part of the metallurgical vessel and thereby also the temperature distribution. The top of the smelt reduction unit is located at or near the roof of the smelt reduction unit, just below the cyclone part.

Preferably, the supply means are adjusted to mix the oxygen gas and the combustible gas before entering the cyclone part. This is beneficial since this premixing increases the control of the mixture that is introduced into the cyclone part of the metallurgical vessel.

Preferably, a group of oxygen gas outlets is surrounding one or more combustible gas outlets. Preferably, a group of combustible gas outlets is surrounding one or more oxygen gas outlets. These embodiments both have the advantage that the mixture will be premixed just before being introduced into the cyclone part, even further improving control. A further advantage is that the mixture will be evenly distributed into the cyclone part.

The invention will hereinafter be further elucidated with reference to the drawing of an exemplary embodiment of an apparatus operating according to the invention that

is not limiting as to the appended claims.

In the drawing:

- Figure 1 shows an overview of the metallurgical vessel;
- Figure 2 shows a top view of the configuration of the supply means in the wall
5 of the cyclone part;

Whenever in the figures the same reference numerals are applied, these numerals refer to the same parts.

Figure 1 shows an overview of the metallurgical vessel according to the process disclosed in patent application EP-A-0 726 326, wherein a metallurgical vessel 1 is applied with on top of the metallurgical vessel 1 a cyclone part 10. Figure 1 clearly shows the introduction point 7 where oxygen gas or a mixture of oxygen gas and a combustible gas is injected in the smelt cyclone 10 at the top of the metallurgical vessel 1. Further figure 1 shows the bath of molten iron 2, a layer of slag 3, the introduction points for carbon containing material 5 and metalliferous feed 4, iron outlet
10 8, slag outlet 9 and the reaction gases outlet 11. For this invention only the introduction point of the oxygen gas 7 or a mixture of oxygen gas and a combustible gas 7 are of importance.

Figure 2 shows, in a top view, an example of the position of the supply means 12 in the surrounding wall 13 of the cyclone part 10. In this example six supply means 12
20 are symmetrically distributed around the circumference of the surrounding wall 13 of the cyclone part 10. This has found to give good results with respect to the control of the temperature in the cyclone part 10. Naturally, other configurations may be possible.

Although the invention has been discussed in the foregoing with reference to
25 exemplary embodiments of the invention, the invention is not restricted to these particular embodiments which can be varied in many ways without departing from the invention. The discussed exemplary embodiments shall therefore not be used to construe the appended claims strictly in accordance therewith. On the contrary, the embodiments are merely intended to explain the wording of the appended claims,
30 without intent to limit the claims to these exemplary embodiments. The scope of protection of the invention shall therefore be construed in accordance with the appended claims only, wherein a possible ambiguity in the wording of the claims shall be resolved using these exemplary embodiments.

CLAIMS

1. Apparatus for the production of molten iron comprising a metallurgical vessel (1) having a surrounding wall (13), a cyclone part (10) provided on top of a smelt reduction part, the cyclone part (10) being in open connection with the smelt reduction part and having at least one supply means (7, 12) around the circumference of the surrounding wall (13) adjusted to introduce oxygen gas into the cyclone part (10), **characterised in that** the at least one supply means (7, 12) is further adjusted to introduce a mixture of oxygen gas and a combustible gas.
2. Apparatus for the production of molten iron according to claim 1, **characterised in that** the combustible gas is selected from the group of coke oven gas, converter gas, natural gas, hydrogen gas and liquefied petroleum gas.
3. Apparatus for the production of molten iron according to claim 2, **characterised in that** the combustible gas contains less than 20% (v/v) nitrogen gas.
4. Apparatus for the production of molten iron according to anyone of the claims 1 to 3, **characterised in that** the supply means (7, 12) are located at the top of the smelt reduction part.
5. Apparatus for the production of molten iron according to anyone of the claims 1 to 3, **characterised in that** the supply means (7, 12) are symmetrically distributed over the circumference of the surrounding wall (13) of the cyclone part (10).
6. Apparatus for the production of molten iron according to anyone of the claims 1 to 4, **characterised in that** the supply means (7, 12) are symmetrically distributed over the circumference of the surrounding wall (13) at the top of the smelt reduction part.
7. Apparatus for the production of molten iron according to anyone of the claims 1 to 6, **characterised in that** the supply means (7, 12) are adjusted to mix the oxygen gas and the combustible gas before entering the cyclone part (10).
8. Apparatus for the production of molten iron according to anyone of the claims 1 to 7, **characterised in that** the supply means (7, 12) are configured such that a

group of oxygen gas outlets is surrounded by one or more combustible gas outlets.

- 5 9. Apparatus for the production of molten iron according to anyone of the claims 1 to 8, **characterised in that** the supply means (7, 12) are configured such that a group of combustible gas outlets is surrounded by one or more oxygen gas outlets.
- 10 10. Method of producing molten iron by means of a metallurgical vessel (1) having a surrounding wall (13), a cyclone part (10) provided on top of a smelt reduction part, the cyclone part (10) being in open connection with the smelt reduction part and having at least one supply means (7, 12) around the circumference of the surrounding wall (13) introducing oxygen gas into the cyclone part (10), **characterised in that** a mixture of oxygen gas and a combustible gas is
15 introduced by means of the at least one supply means (7, 12).
- 20 11. Method of producing molten iron according to claim 10, **characterised in that** the combustible gas is selected from the group of coke oven gas, converter gas, natural gas, hydrogen gas and liquefied petroleum gas.
- 25 12. Method of producing molten iron according to claim 11, **characterised in that** the combustible gas contains less than 20% (v/v) nitrogen gas.
- 30 13. Method of producing molten iron according to anyone of the claims 10 to 12, **characterised in that** the supply means (7, 12) are symmetrically distributed over the circumference of the surrounding wall (13) of the cyclone part (10).
- 35 14. Method of producing molten iron according to anyone of the claims 10 to 12, **characterised in that** the supply means (7, 12) are symmetrically distributed over the circumference of the surrounding wall (13) at the top of the smelt reduction part.
15. Method of producing molten iron according to anyone of the claims 10 to 14, **characterised in that** the oxygen gas and the combustible gas are mixed by the supply means (7, 12) before entering the cyclone part (10).

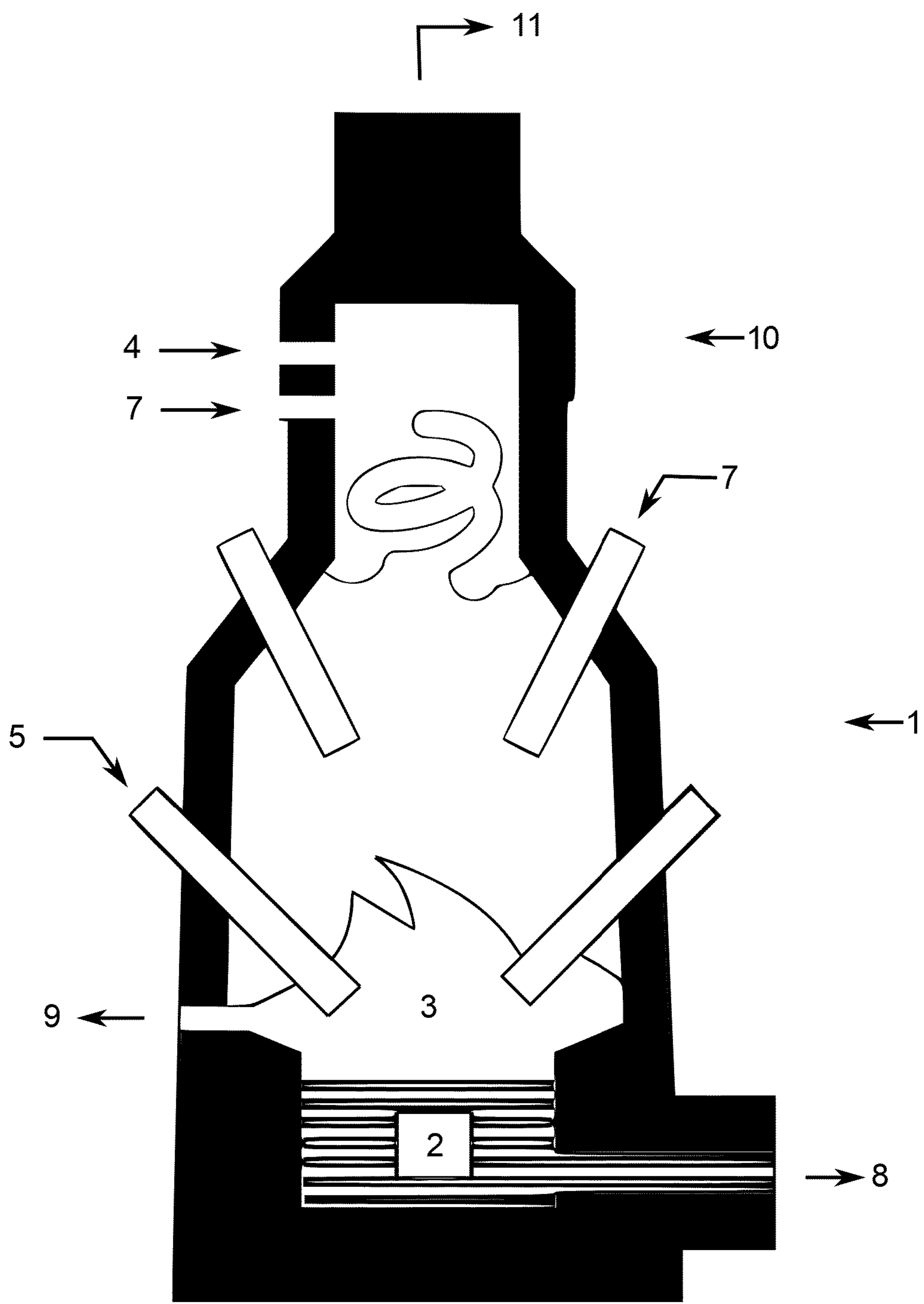


Figure 1

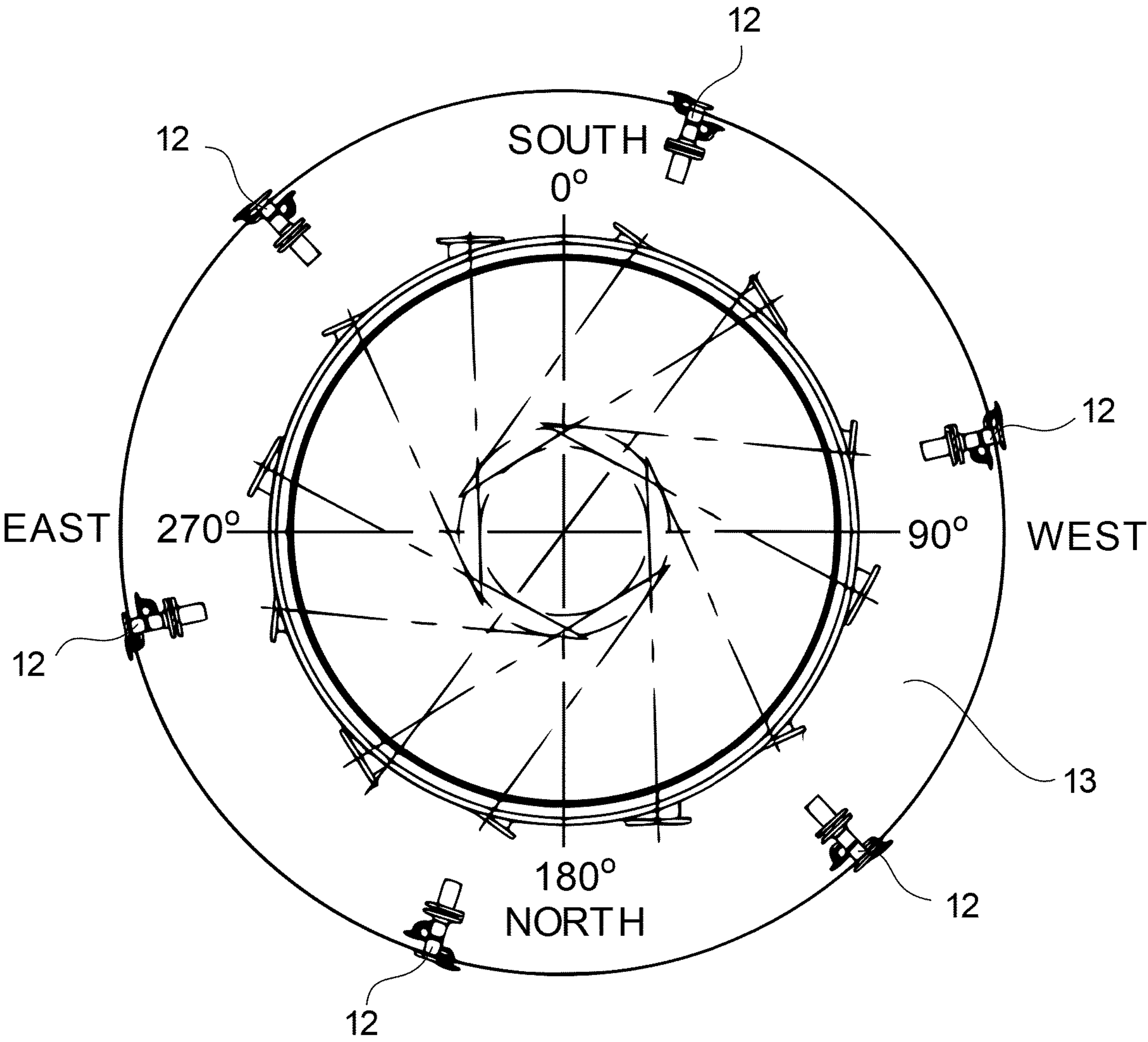


Figure 2

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2020/083697

A. CLASSIFICATION OF SUBJECT MATTER

INV. C21B11/08 C21B13/00 C21C5/56
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	US 4 087 274 A (EDENWALL INGVAR A O ET AL) 2 May 1978 (1978-05-02) figures 1-3 column 7, line 54 - column 8, line 10 -----	1-7, 10-15
X A	EP 0 690 136 A1 (HOOGOVS GROEP BV [NL]) 3 January 1996 (1996-01-03) claims 1-6 -----	1-7, 10-15 8,9
A	CN 86 102 198 A (LI SHIYUAN) 23 December 1987 (1987-12-23) figure 2 -----	1-15
A	WO 2019/185866 A1 (TATA STEEL NEDERLAND TECH B V [NL]) 3 October 2019 (2019-10-03) claims 1,2 -----	1-15



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

17 February 2021

Date of mailing of the international search report

26/02/2021

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

Gimeno-Fabra, Lluís

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2020/083697

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 4087274	A	02-05-1978	AT 369429 B 27-12-1982
		AU 498857 B2 29-03-1979	
		BR 7604353 A 26-07-1977	
		CA 1077723 A 20-05-1980	
		DD 126712 A5 10-08-1977	
		DE 2629743 A1 20-01-1977	
		DE 2660884 C2 11-04-1985	
		DK 288176 A 05-01-1977	
		ES 449348 A1 01-12-1977	
		FI 761947 A 05-01-1977	
		FR 2326475 A1 29-04-1977	
		GB 1554263 A 17-10-1979	
		IT 1065052 B 25-02-1985	
		JP S528905 A 24-01-1977	
		JP S5726335 B2 03-06-1982	
		LU 75298 A1 23-02-1977	
		MY 8200270 A 31-12-1982	
		NL 7607352 A 06-01-1977	
		NO 143068 B 01-09-1980	
		NO 143165 B 15-09-1980	
		US 4087274 A 02-05-1978	

EP 0690136	A1	03-01-1996	AT 199940 T 15-04-2001
		AU 691908 B2 28-05-1998	
		BR 9503034 A 11-06-1996	
		CA 2153081 A1 02-01-1996	
		CN 1123840 A 05-06-1996	
		DE 69520391 T2 06-09-2001	
		EP 0690136 A1 03-01-1996	
		ES 2156188 T3 16-06-2001	
		KR 0156813 B1 16-11-1998	
		NL 9401103 A 01-02-1996	
		PL 309418 A1 08-01-1996	
		RU 2143005 C1 20-12-1999	
		US 5639293 A 17-06-1997	
		ZA 955312 B 09-02-1996	

CN 86102198	A	23-12-1987	NONE

WO 2019185866	A1	03-10-2019	AU 2019240893 A1 08-10-2020
		BR 112020018881 A2 29-12-2020	
		CN 111989412 A 24-11-2020	
		EP 3775296 A1 17-02-2021	
		KR 20200136909 A 08-12-2020	
		US 2021040572 A1 11-02-2021	
		WO 2019185866 A1 03-10-2019	
