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(54) **Title:** METHOD AND EQUIPMENT TO PRODUCE A SYNGAS FROM WASTES, PREFERABLY INDUSTRIAL OR MUNICIPAL WASTES AND THEIR DELIVERABLES

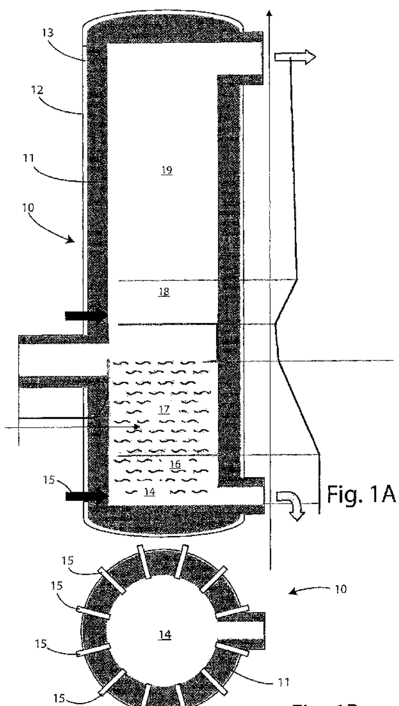

Fig. 1A

Fig. 1B

(57) **Abstract:** The invention concerns a method to produce a syngas from wastes, preferably municipal wastes or derived fuel from wastes, wherein: - wastes are fed into a reactor at a temperature between 20 and 800°C to form a fixed bed; - oxygen is injected at the bottom of said fixed bed to react with said wastes in an oxidation reaction to give a syngas, the temperature of the bottom of said fixed bed being maintained in a range between 1400 and 2000°C, preferably between 1400 and 1600°C, to form a melting area at the bottom of said fixed bed, where melting of inert and metal compounds contained in said wastes is obtained; - said syngas flows through said fixed bed, causing an endothermic cracking reaction and a progressive lowering of the temperature, to form a gasification area, until reaching a temperature of around 800°C at the top of said fixed bed; - oxygen is injected inside said reactor, above said fixed bed,

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causing oxidation and increasing the temperature up to 1200°C, to form a post-reheating area; - a stabilizing area is provided at the top of said reactor, where the temperature ranges from 1050 to 1200°C; and wherein - the temperature profile at the bottom and along the height of said reactor is controlled by injection of an inert gas flow at the bottom of said fixed bed, together with oxygen.

Method and equipment to produce a syngas from wastes, preferably industrial or municipal wastes and their deliverables

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The present invention concerns a method and equipment to produce a syngas from wastes, preferably industrial or municipal wastes and their deliverables.

More precisely, the invention relates to a method and equipment design to produce synthesis gas which, when used as feedstock for Fisher-Tropsch, methanol or ammonia plants, will enable to substitute natural gas or other hydrocarbons with waste or waste derived fuel (also known as RDF, standing for refuse derived fuel).

As it is known, the growth of population and wealth increase on a worldwide basis have resulted in a dramatic rise of the amount of produced waste.

According to the prior art, conventional waste management is driven by minimizing the costs of collection and land-filling versus recycling and incineration, although more and more waste material are recycled (paper, some metals, etc.).

New ideas are emerging to use waste or what is left from conventional recycle as-new resource by recycling the materials. Production of syngas from wastes by high temperature gasification is following into such a model of circular economy.

Such approach is intended to save resources, mainly hydrocarbons, and minimize emissions and pollution, and consequently protect the environment also in terms of CO_2 emissions.

A proper gasification reactor needs to be designed for such a conversion in order to adhere to the requirements imposed on the syngas composition to be used for a subsequent production of chemicals, requirements quite different from the use of such a syngas as fuel.

Prior art gasification reactors using waste or waste derived fuel as feedstock have accomplished to varying degrees of effectiveness and efficiency in the past, however the production of syngas to produce urea or methanol is yet untapped.

The main technical barriers to solve in order to have a proper design of such reactor are:

- waste conversion needs to be carried out with O_2 in order to have a syngas of high quality. Air based reactor cannot be directly used to produce chemicals;

- syngas outlet temperature has to be high enough, 1050-1150°C, in order to avoid reformation of noxious products and to limit the content of hydrocarbons. Presence of hydrocarbons makes more complicated the downstream process and requires a separate reforming step to convert such hydrocarbons into H_2 and CO;

- temperature profile along the height of the reactor has to be properly controlled to avoid internal overheating and maintain a conversion efficiency higher than 99%;

- temperature profile on the horizontal cross section of the reactor has to be uniform in order to have a homogeneous conversion of the feedstock;

- slag temperature at the bottom of gasification reactor has to be high enough, 1400-1600°C, in order to maintain the slag in a liquid phase with a carbon content of less than 1%;

- reactor pressure needs to be slightly above atmospheric pressure to enhance the plant safety;

- because of the high volume of syngas required for chemical productions, the reactor design is preferably standardized for a specific capacity through modular approach. Product capacity will be achieved by multiple reactors working in parallel.

In view of all above, it is evident the need for a method and equipment to produce a syngas to be used for a subsequent production of chemicals, starting from wastes.

In this context it is proposed the solution according to the present invention, with the aim of providing for a method and equipment design to produce a syngas which is suitable to be used as feedstock for Fischer-Tropsch, methanol, ammonia or urea plants, totally replacing the use of hydrocarbons.

Another object of this invention is to minimize emissions associated with waste disposal. Another object of this invention is to recycle the waste carbon matrix into valuable products, such as urea, methanol, bio-fuels, capturing the CO_2 otherwise emitted by these plants.

Yet another object of this invention is to provide a cost effective method to make chemicals.

A further object of this invention is to provide a much cleaner and more uniform syngas composition than current processes provide.

These and other results are achieved according to the present invention by proposing a gasification reactor design with the following features:

- down flow of the waste feed, located in a proper vertical position, not to lower the outlet syngas temperature, but to obtain a proper temperature vertical profile;

- multiple injection points for the oxygen, to have a proper mixing with the feedstock;

- multiple injection of a gaseous carrier, CO_2 or H_2O or raw gas to better control the temperature along the cross sectional area and the height of the gasification reactor.

It is therefore an aim of the present invention that of realising a method and equipment to produce a syngas from wastes, preferably municipal and/or industrial wastes and their deliverables, allowing for overcoming the limits of the solutions according to the prior art and achieving the previously described technical results.

A further aim of the invention is that said method and equipment to produce a syngas from wastes can be realised with substantially limited costs, as far as both the construction and the operative costs are concerned.

Not last aim of the invention is that of realising a method and equipment to produce a syngas from wastes being substantially simple, safe and reliable.

It is therefore a first specific object of the present invention a method to produce a syngas from wastes, preferably municipal wastes or derived fuel from wastes, wherein:

- wastes are fed into a reactor at a temperature between 20 and 800°C to form a fixed bed;

- oxygen is injected at the bottom of said fixed bed to react with said wastes in an oxidation reaction to give a syngas, the temperature of the bottom of said fixed bed being maintained in a range between 1400 and 2000°C, preferably between 1400 and 1600°C, to form a melting area at the bottom of said fixed bed, where melting of inert and metal compounds contained in said wastes is obtained;

- said syngas flows through said fixed bed, causing an endothermic cracking reaction and a progressive lowering of the temperature, to form a gasification area, until reaching a temperature of around 800°C at the top of said fixed bed;

- oxygen is injected inside said reactor, above said fixed bed, causing oxidation and increasing the temperature up to 1200°C, to form a post-reheating area;

- a stabilizing area is provided at the top of said reactor, where the temperature ranges from 1050 to 1200°C;

and wherein

- the temperature profile at the bottom and along the height of said reactor is controlled by injection of an inert gas flow at the bottom of said fixed bed, together with oxygen.

Optionally, according to the present invention, natural gas is injected together with oxygen, at the bottom of said fixed bed and/or above said fixed bed.

Preferably, according to the invention, oxygen is injected in a plurality of injection points.

In particular, always according to the present invention, said inert gas can be CO_2.

It is a second specific object of the present invention a n equipment to produce a syngas from wastes, preferably industrial or municipal wastes, according to the method previously defined, comprising a vertical type cylindrical fixed bed reactor with an internal lining with refractory and double steel walls with internal cooling water between the walls.

Preferably, according to the invention a fixed bed of wastes is provided inside said reactor, the height of said fixed bed being set to a level apt to achieve a temperature at its top around 800°C.

In particular, according to the invention, said equipment to produce a syngas from wastes comprises a plurality of lances for O_2 injection, said lances comprising two coaxial conduits, surrounded by a shell for a cooling fluid.

It is a third specific object of the present invention the use of synthesis gas produced according to the method previously defined to produce hydrogen and CO_2.

It is a fourth specific object of the present invention the use of hydrogen produced according to the use of the synthesis gas previously defined to react together with nitrogen to produce ammonia.

It is a fifth specific object of the present invention the use of ammonia produced according to the use of hydrogen previously defined to react with CO_2 to produce urea.

Finally, it is a sixth specific object of the present invention the use of synthesis gas produced according to the method previously defined to produce methanol.

The invention will be disclosed herein below for illustrative, but non limitative purposes, according to a preferred embodiment, with reference in particular to the figures of the enclosed drawing, wherein:

- figure 1A shows a schematic lateral sectional view of a reactor according the present invention, together with the temperature profile along the reactor,

- figure 1B shows a schematic plan sectional view of the reactor of figure 1A,

- figure 2 shows a schematic lateral sectional view of a particular portion of the reactor of figures 1A and 1B, showing the temperature distribution of the fixed bed of wastes in proximity of an oxygen injection lance,

- figure 3 shows a schematic plan sectional view of the reactor of figure 1A, together with the temperature profile at the bottom of the reactor before control,

- figure 4 shows a schematic lateral sectional view of a particular portion of the reactor of figures 1A and 1B, showing the temperature distribution of the fixed bed of wastes in proximity of an inert gas injection lance,

- figure 5 shows a schematic plan sectional view of the reactor of figure 1A, together with the temperature profile at the bottom of the reactor after control, and

- figure 6 shows a schematic lateral sectional view of the reactor of figures 1A and 1B, together with a schematic view of the control architecture.

Making reference to the figures, the method and equipment to produce syngas from wastes proposed according to the present invention, in order to obtain a syngas suitable for the production of chemicals must achieve the following targets:

- avoid hydrocarbons, tars and generally speaking heavy molecular weight compounds,

- maximize the hydrogen and carbon monoxide concentration,

- maximize the hydrogen and carbon monoxide quantity.

To achieve the first target above, it is necessary to operate at high temperature.

To obtain the necessary temperature level and to maximize the concentration of valuable elements, namely hydrogen and carbon monoxide, in the syngas, it is necessary to use pure oxygen as gasifying agent.

Finally, in order to maximize the hydrogen and carbon monoxide quantity, it is recommendable to select a feedstock with high specific energy content (Lower Heating Value - LHV), typically containing a high amount of non-recyclable plastics (like PVC) and low amount of water.

To implement such a process, a vertical type cylindrical fixed bed reactor 10 is required. The reactor design has an internal lining 11 with special refractory and double steel walls 12 with internal cooling water 13 between the walls 12 (Jacket Cooling system) as safety measure.

All of above operational conditions, pure oxygen and high LHV, might cause under certain circumstances temperatures higher than the necessary and consequential higher wearing of the refractory lining 11 of the reactor 10. In such a case a multiple injection of a gaseous carrier, CO_2 or H_2O, must be provided.

Required temperature profile along the reactor

Making reference to figure 1A, the required process temperature distribution is the following. The temperature at the bottom 14 of the reactor 10 shall be 1600°C to achieve the melting process of the inert and metal compounds inevitably present in the feedstock. Higher temperature is unnecessary for most of household and industrial waste and would cause only additional wearing of the refractory.

The hot flue gas generated by the partial oxidation that occurs at the bottom of the reactor 10 flows through the fixed bed 14, causing the endothermic cracking reaction typical of the gasification, and cooling down. The height of the bed 14 is set to a level suitable to achieve a temperature at its top around 800°C, the minimum temperature needed for the carrying out of most of the gasifying process.

At the exit from the fixed bed 14 a fraction of the syngas is burnt with oxygen to reach a temperature above 1100°C and so complete the conversion of the most resistant compounds such as naphthalenes and paraffines.

The ideal horizontal distribution of the temperature must be uniform.

To get as close as possible to this objective, oxygen is injected in the reactor 10 by means of a set of lances 15 arranged radially as shown in Figure 1B.

Inside the gasification reactor 10 different areas may be identified (starting from the bottom of the reactor):

- a melting area 16, at a temperature ranging from 1400 to 1600°C,
- a gasification area 17 at a temperature ranging from 800 to 1600°C,
- a post-reheating area 18 at a temperature ranging from 800 to 1200°C,
- a stabilizing area 19 at a temperature ranging from 1050 to 1250°C.

Real temperature distribution

The amount of oxygen injected at the bottom of the reactor 10 is in relation with the waste composition and controls the system throughput. As a matter of fact, the process temperature profile is a result not so controllable by the oxygen amount.

In case of a temperature at the bottom of the reactor 10 lower than 1600°C, resulting from a low LHV feedstock, an amount of natural gas can be injected through a second channel 20 of the oxygen lances 15. This channel is used also for the reactor warm up and a minimum flow must be kept in any case to preserve from clogging caused by the melted inert (purging gas).

Oxygen injected by the lances 15 impacts on the material that forms the bed 14 and, despite the high speed, is partially turned back. It reacts with violence in proximity of the refractory 11, especially in presence of natural gas. As shown in figure 2, this causes a non uniform distribution of the temperature, with overheated zones on the refractory lining 11 around the heads of the lances 15, where the temperature can easily exceed 2000°C. This effect is worsened by high LHV material that causes a general increasing of the temperatures at the bottom of the reactor 10 and generally a more compact and difficult to penetrate bed 14. The resulting temperature profile in the cross-sectional area of the reactor 10 is shown in figure 3.

Use of inert gas to control the temperature

To reduce the undesired overheating, preserving the efficiency of the reactor 10, a inert gas flow can be used. A small amount of inert gas at ambient temperature is introduced at low speed instead of the purging natural gas, which creates a cushion around the lances heads in order to decrease the local temperature.

In case of high LHV material, the inert gas amount can be increased to create a wider cooling effect to stabilize the temperature profile.

In case of chemical application of the syngas (as for urea production) a certain amount of CO_2 is usually available as by-product. The use of this inert gas is generally preferable not to alter too much the chemical species present at the outlet in the syngas. Alternatively, in case it is possible, nitrogen can be used.

The resulting cross-sectional profile is shown in figures 4 and 5.

Table 1 shows the effect of CO_2 injection in case of a high calorific waste.

Case 1 represents the condition without inert flow, Case 2 with low amount of CO_2 (cushion effect only), Case 3 with CO_2 amount set to reduce the calculated bottom temperature to the required working condition.

Table 1

Effect of CO_2 injection flow on syngas composition

	M. U.	Case 1	Case 2	Case 3
Waste input	t/h	10,0	10,0	10,0
Waste LHV	MJ/kg	20,97	20,97	20,97
CO_2 input	Nm^3/h	0	330	2000
O_2 input bottom side	Nm^3/h	3380	3380	3380
O_2 input re-heating	Nm^3/h	650	650	750
Bottom side average temperature	°C	1992	1922	1606
H_2	% vol	42,27	40,85	33,86
CO	% vol	44,73	45,26	47,14
CO_2	% vol	8,28	9,18	14,29
Syngas flow	Nm3/h	16858	16757	17568
Syngas LHV	MJ/Nm 3	10,14	10,05	9,52

As shown in Table 1, the injection of small amount of inert gas does not change significantly the syngas quantity and quality, meanwhile increasing the CO_2 flow the balance $CO/CO_2/H_2$ in the produced syngas changes in a sensible way.

If the H_2/CO_2 ratio is evaluated after the water gas shift this ratio is moving from 1,64 to 1,32 for case 3.

Control Strategy

In order to control and maintain the proper temperature profile and cross-sectional distribution at the bottom and at the top of the reactor, the following control philosophy is adopted as shown in Figure 6.

The control of the reactor's bottom temperature is carried out by means of a computerized system (fuzzy logic) that takes in account the following parameters:

- waste type,
- throughput,
- bottom temperature by thermal camera (TV),
- refractory temperature (T1),
- intermediate temperature (T2),
- operator setting.

The system regulates the natural gas or inert gas injection flows by means of motorized valves.

The operator can select if to activate or deactivate the system and the strength of intervention (wall protection or process temperature reduction).

The control of the reactor's top temperature is carried out by means of a computerized PID (Proportional Integral Derivative) controller that takes into account the following parameters:

- top side temperature (T3),
- intermediate temperature (T2),
- hydrogen content,
- operator setting.

The system acts on the natural gas and oxygen injection by means of motorized valves.

The operator can select if to use only the syngas combustion to increase the temperature or inject natural gas.

This second option is used in case of need to preserve the hydrogen content of the syngas, especially in case of low LHV feedstock.

The present invention was disclosed for illustrative, non limitative purposes, according to a preferred embodiment thereof, but it has to be understood that any variations and/or modification can be made by the persons skilled in the art without for this reason escaping from the relative scope of protection, as defined in the enclosed claims.

CLAIMS

1) Method to produce a syngas from wastes, preferably municipal wastes or derived fuel from wastes, wherein:

- wastes are fed into a reactor at a temperature between 20 and 800°C to form a fixed bed;

- oxygen is injected at the bottom of said fixed bed to react with said wastes in an oxidation reaction to give a syngas, the temperature of the bottom of said fixed bed being maintained in a range between 1400 and 2000°C, preferably between 1400 and 1600°C, to form a melting area at the bottom of said fixed bed, where melting of inert and metal compounds contained in said wastes is obtained;

- said syngas flows through said fixed bed, causing an endothermic cracking reaction and a progressive lowering of the temperature, to form a gasification area, until reaching a temperature of around 800°C at the top of said fixed bed;

- oxygen is injected inside said reactor, above said fixed bed, causing oxidation and increasing the temperature up to 1200°C, to form a post-reheating area;

- a stabilizing area is provided at the top of said reactor, where the temperature ranges from 1050 to 1200°C;

and wherein

- the temperature profile at the bottom and along the height of said reactor is controlled by injection of an inert gas flow at the bottom of said fixed bed, together with oxygen.

2) Method to produce a syngas from wastes according to claim 1, characterized in that natural gas is injected together with oxygen, at the bottom of said fixed bed and/or above said fixed bed.

3) Method to produce a syngas from wastes according to claim 1 or 2, characterized in that oxygen in injected in a plurality of injection points.

4) Method to produce a syngas from wastes according to any of the preceding claims, characterized in that said inert gas is CO_2.

5) Equipment to produce a syngas from wastes, preferably industrial or municipal wastes, according to the method of any of claims 1 - 4, characterised in comprising a vertical type cylindrical fixed bed reactor (10) with an internal lining (11) with refractory and double steel walls (12) with internal cooling water (13) between the walls (12), a fixed bed (14) of wastes being provided inside said reactor, the height of said fixed bed (14)

being set to a level apt to achieve a temperature at its top around 800°Cand a plurality of lances being provided for O_2 injection, and a plurality of lances being provided for injection of an inert gas, means for controlling the temperature being provided at the bottom (16) of the reactor (10), said means for controlling the temperature being apt to maintain the temperature in the range 1400-2000°C, preferably 1400-1600°C, means for controlling the temperature being provided in the area (18) over the top of the fixed bed (17), said means for controlling the temperature being apt to maintain the temperature in the range 800-1200°C, preferably 1100-1200°C, and means for controlling the temperature being provided at the top of the reactor (10), said means for controlling the temperature being apt to maintain the temperature in the range 1050-1250°C.

6) Equipment to produce a syngas from wastes according to claim 5, characterized in that said lances comprise two coaxial conduits, surrounded by a shell for a cooling fluid.

7) Use of synthesis gas produced according to claims 1-4 to produce hydrogen and CO_2.

8) Use of hydrogen produced according to claim 7 to react together with nitrogen to produce ammonia.

9) Use of ammonia produced according to claim 8 to react with CO2 to produce urea.

10) Use of synthesis gas produced according to claims 1-4 to produce methanol.

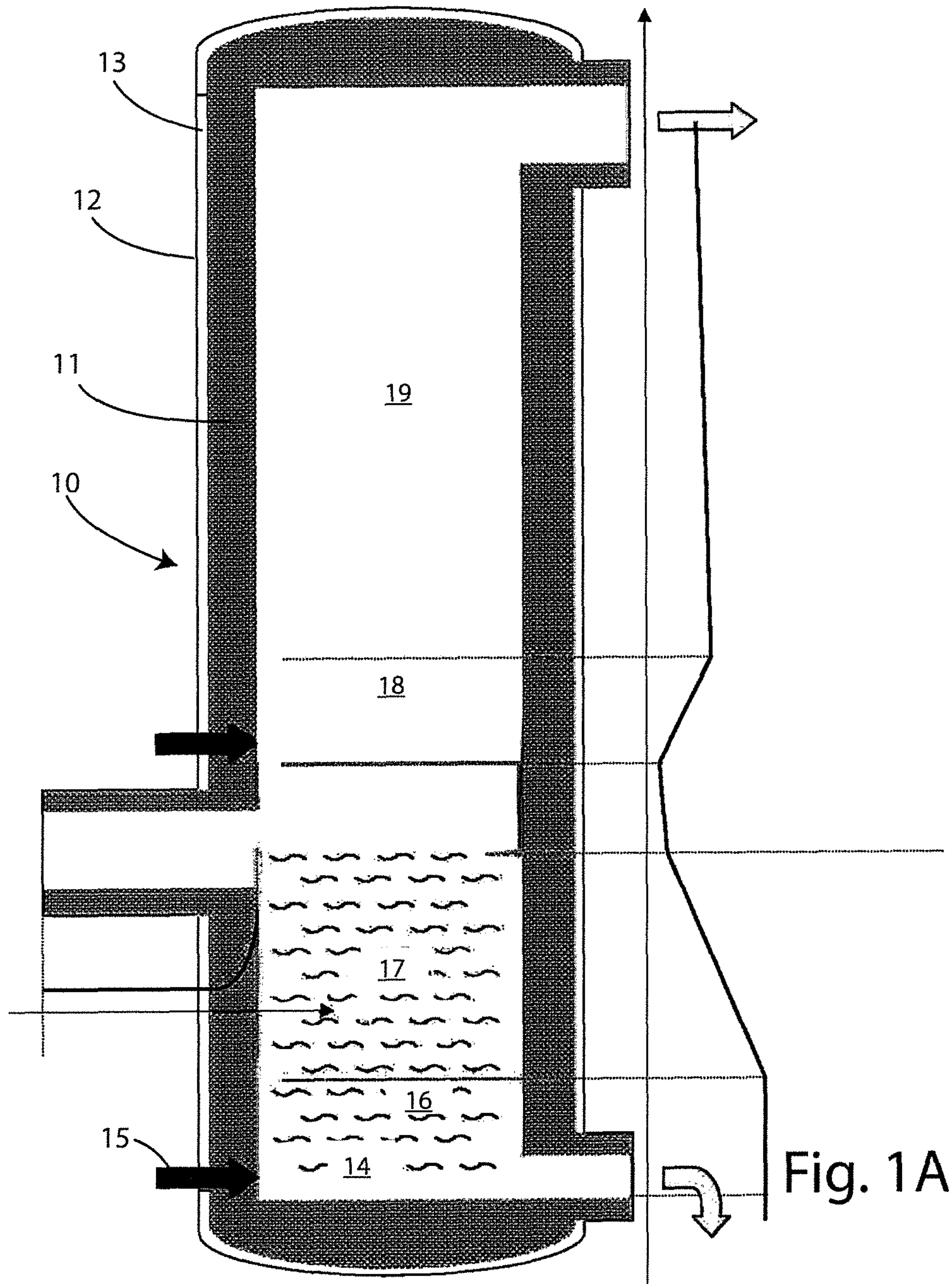

Fig. 1A

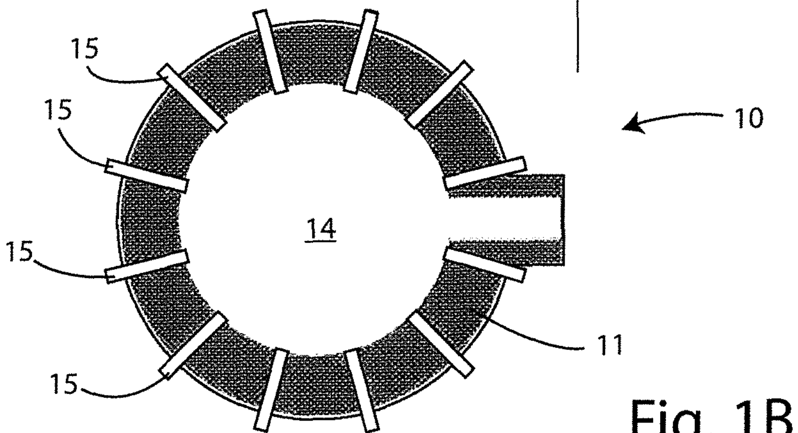

Fig. 1B

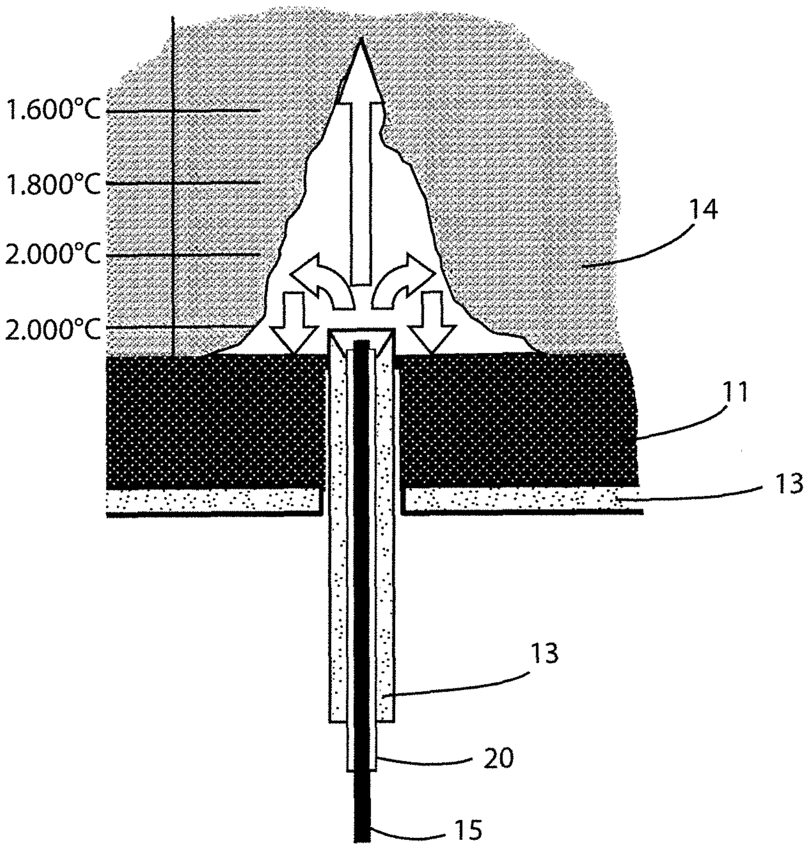

Fig. 2

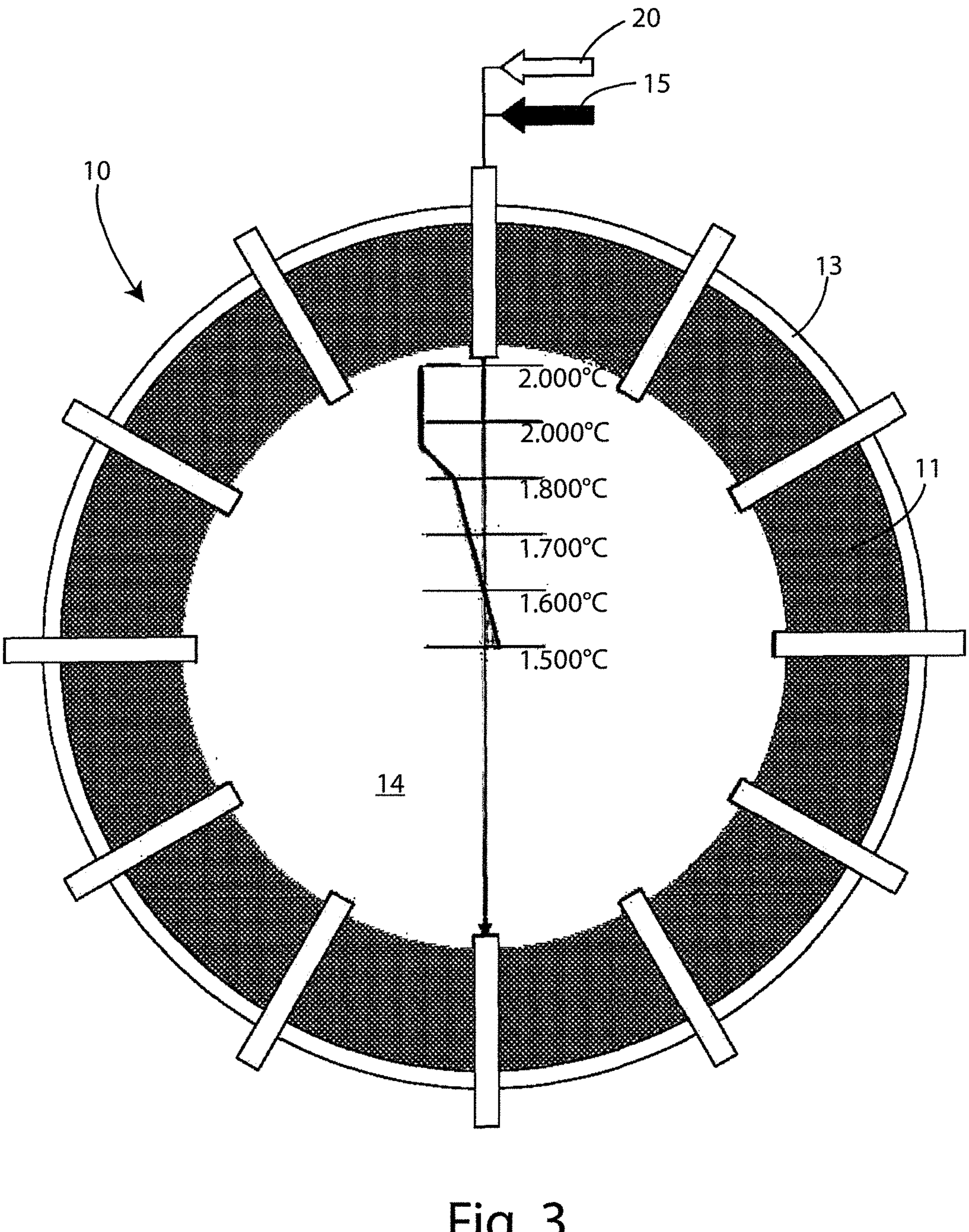

Fig. 3

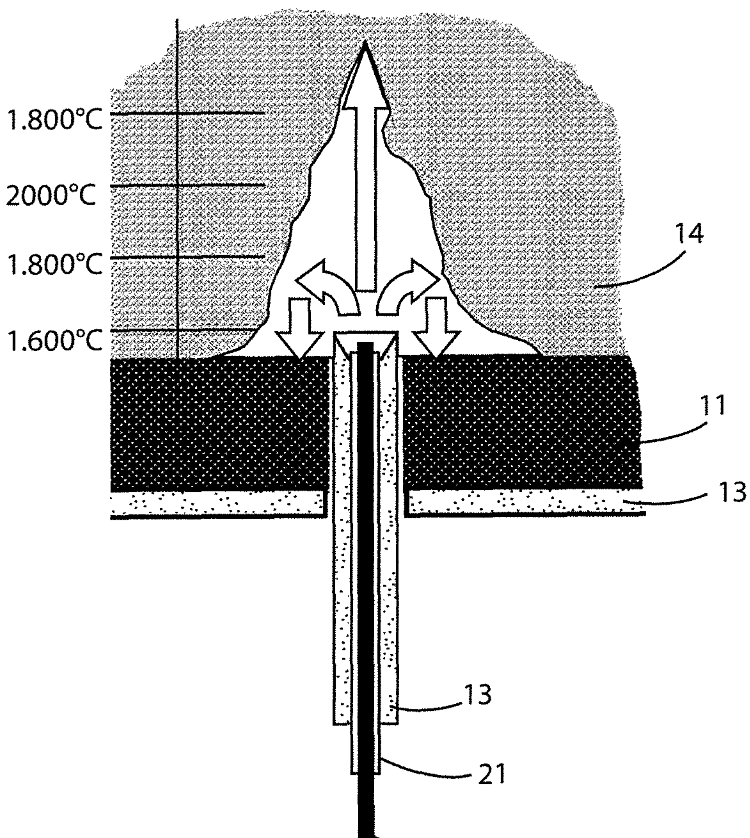

Fig. 4

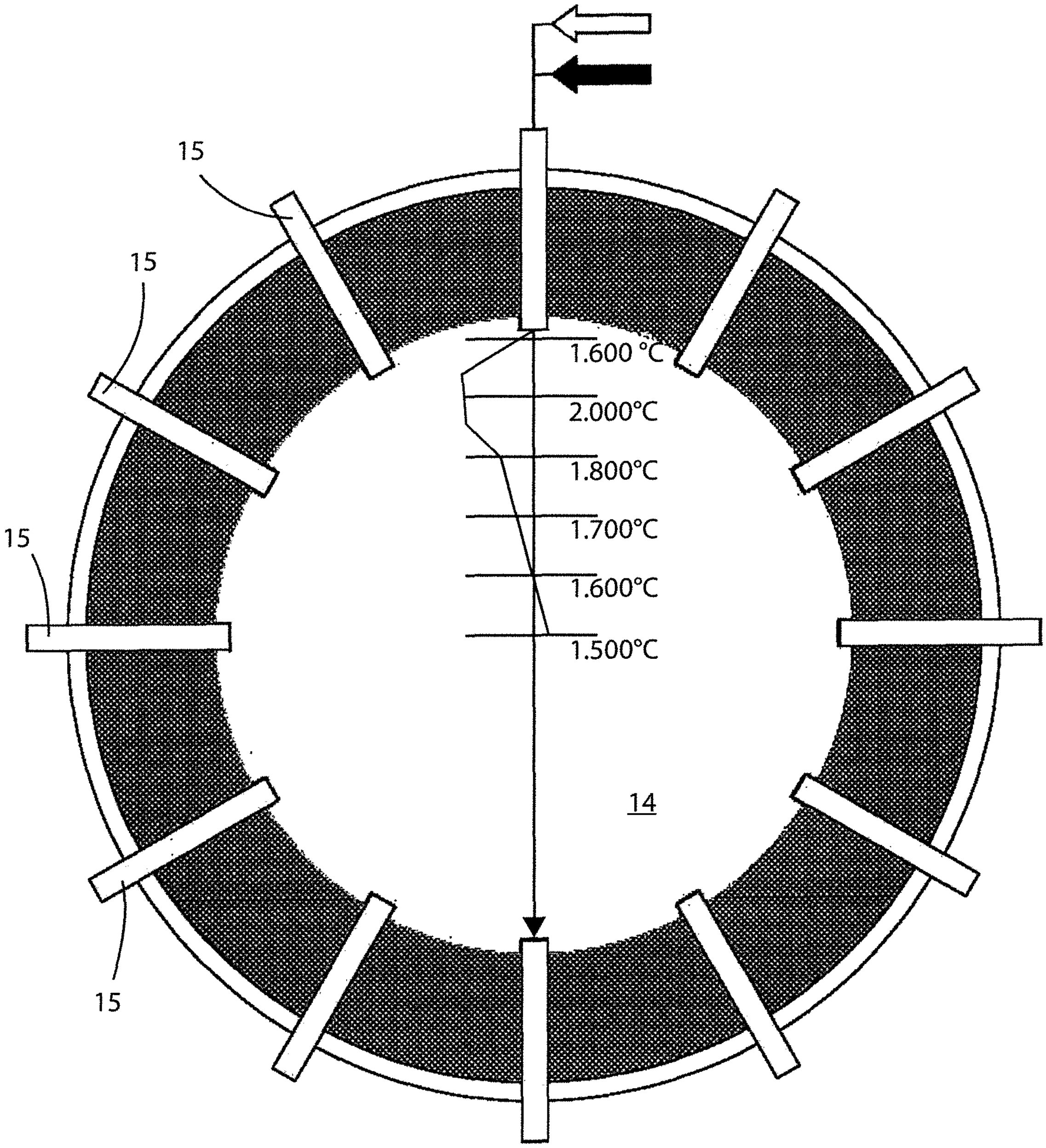

Fig. 5

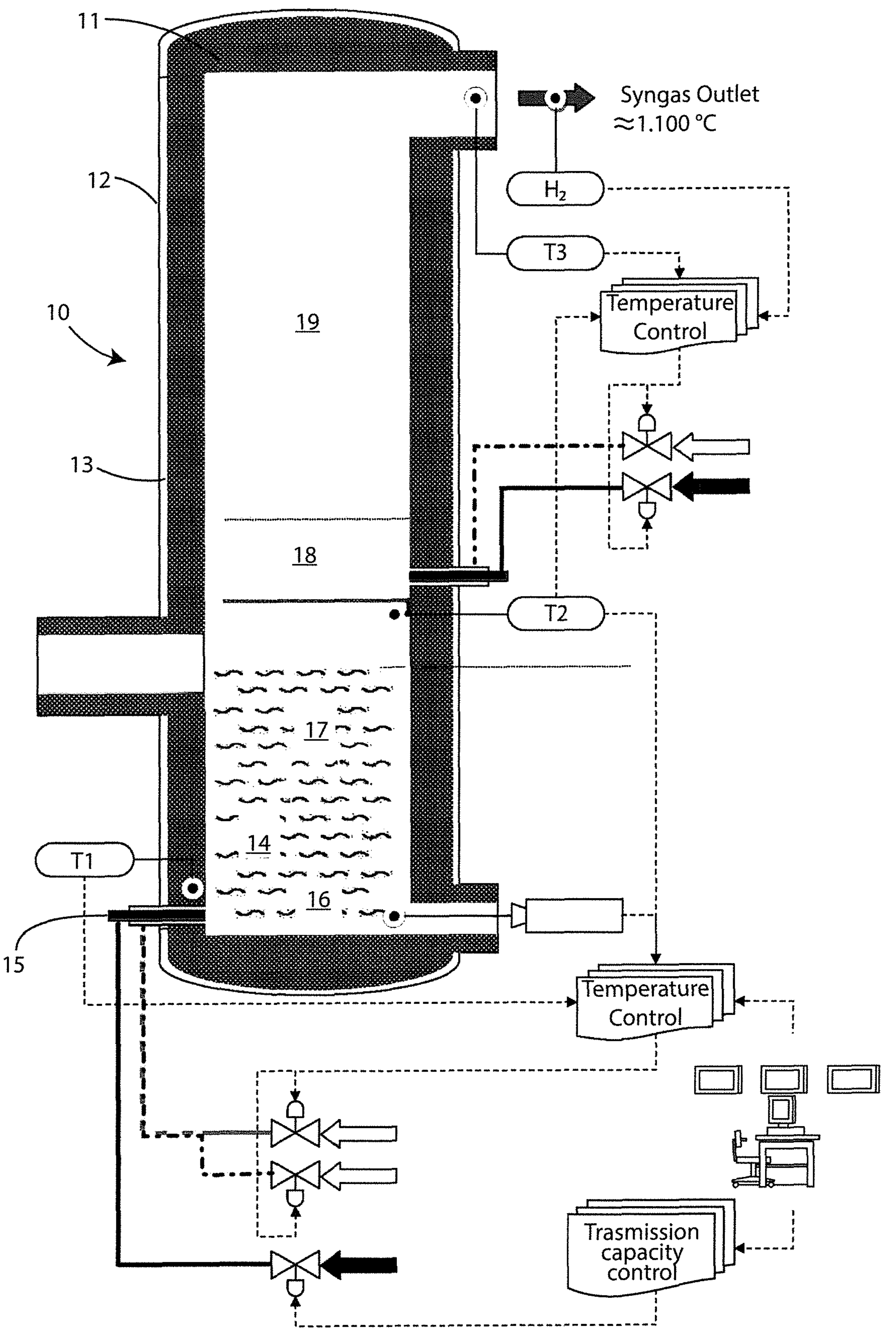
11
Syngas Outlet
≈1.100 °C
12
H2
T3
Temperature Control
10
19
13
18
T2
17
14
T1
16
15
Temperature Control
Trasmission capacity control

Fig. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/IT2017/000220

A. CLASSIFICATION OF SUBJECT MATTER
INV. C10J3/08 C10J3/72 C10J3/76 C10K3/00
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)
C10J C10K

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 Y	EP 0 277 935 A1 (VOEST ALPINE AG) 10 August 1988 (1988-08-10) figure 1 pages 2-3	1-10 1
A	DE 10 2007 006979 A1 (UNIV FREIBERG TECH BERGAKAD [DE]) 14 August 2008 (2008-08-14) the whole document	1-4
A	WO 03/006585 A1 (CALDERON SYNGAS COMPANY [US]) 23 January 2003 (2003-01-23) the whole document figure 2	1-4
A	EP 0 790 291 A2 (THERMOSELECT AG [LI]) 20 August 1997 (1997-08-20) the whole document claims 1-13	1-4

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[X] Further documents are listed in the continuation of Box C.

[X] 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
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Date of the actual completion of the international search	Date of mailing of the international search report
19 February 2018	27/02/2018

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Lachmann, Richard

3

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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