



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
22.03.2023 Bulletin 2023/12

(51) International Patent Classification (IPC):
C10K 3/00 (2006.01) **C10B 47/04** (2006.01)
C10B 49/02 (2006.01) **C10J 3/34** (2006.01)

(21) Application number: **21196854.0**

(52) Cooperative Patent Classification (CPC):
C10K 3/005; C10B 47/04; C10B 53/02;
C10B 57/18; C10J 3/06; C10J 3/84; C10B 49/02;
C10J 3/34; C10J 2300/0916; C10J 2300/0956;
C10J 2300/1846

(22) Date of filing: **15.09.2021**

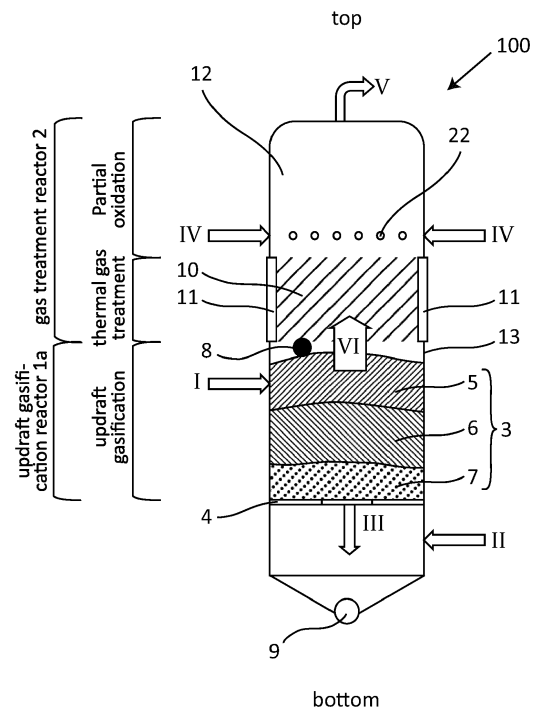
(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

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(54) **A METHOD AND A DEVICE TO PRODUCE LOW-TAR- AND LOW-DUST PRODUCT GAS**

(57) Method to produce a product gas with low tar and dust contents from solid biomass, biogenic residues and/or organic waste fractions with a gas production device (100), the gas production device (100) comprising: a fuel conversion reactor (1a, 1b), which is an updraft gasification reactor (1a) or a pyrolysis reactor (1b); and a gas treatment reactor (2) located downstream the fuel conversion reactor (1a, 1b); wherein the fuel conversion reactor (1a, 1b) is close-coupled with the gas treatment reactor (2); wherein the fuel conversion reactor (1a, 1b) comprises a space to contain a fuel bed (3) above a grate (4); wherein the gas treatment reactor (2) comprises the following: a POX zone (12), and at least one POX nozzle (22) for supplying an oxidiser into the POX zone (12); and a gas heating zone (10) fluidic located between the space to contain the fuel bed (3) and the POX zone (12); wherein the method comprises the following steps: Creating an initial product gas (VI) in the fuel conversion reactor (1a, 1b); Heating the initial product gas, which is created in the fuel conversion reactor (1a, 1b), in the gas heating zone (10); Combusting the heated initial product gas in the gas treatment reactor (2) partially in the POX zone (12) of the gas treatment reactor (2) by injecting or supplying an oxidiser through the POX nozzles (22) into the POX zone (12).

Fig. 1



Description

BACKGROUND

1. Field of the Invention

[0001] The invention relates to a method and a device to produce a product gas with a low tar and dust content from a fuel, e.g. solid biomass, biogenic residues and/or organic waste.

2. State-of-the-Art

[0002] Pyrolysis and gasification can convert carbon-containing materials into useful chemical products. These products typically involve product gas, which can be combusted for the production of heat and electricity or can undergo further chemical reactions. For instance, the product gas can be used as a fuel or as an intermediate in creating synthetic natural gas (SNG) or for the production of methanol, hydrogen, waxes, synthetic hydrocarbon fuels or oil products, or as a feedstock for other chemical processes.

[0003] Coal, waste or biomass based fuels are typically used as input materials for the production of product gas based on gasification or pyrolysis. In biomass gasification or pyrolysis processes or methods, wood, forest residues or energy crops, but also agricultural waste and biogenic residues such as straw or husks and organic waste fractions are used, for example.

[0004] Several types of gasification and pyrolysis methods and apparatuses have been developed to achieve efficient conversion of biomass into clean gaseous products. Many of the gasification processes known in the art have failed due to insufficient attention to efficient tar destruction / conversion in the product gas produced.

Gasification reactors

[0005] Regarding gasification, an initial fuel is typically converted in a fixed-bed, moving-bed or in a fluidised-bed reactor. Fixed or moving-bed reactors are typically divided into the following categories: downdraft (fuel and gas move downwards) and updraft (fuel moves downwards and gas flows upwards) reactors.

[0006] Both downdraft and updraft systems can be coupled with a fixed grate or a moving grate where the fuel moves vertically, diagonally or step by step downwards.

[0007] Downdraft gasifiers are typically operated at a stoichiometric air ratio of 0.2 to 0.35, updraft gasifiers typically at an air ratio of 0.18 to 0.3. As gasification agent air, oxygen, steam or mixtures of these gases are used. Typical gasification temperatures in fixed-bed biomass gasification units are in the range of 800 - 1,100°C. Generally, these gasifier-types are used in small-scale energy production (< 10-20 MW fuel power input related to

the net calorific value of the fuel).

[0008] Fluidised-bed reactors can typically be divided into bubbling fluidised-bed, circulating fluidised-bed or entrained flow reactors. In fluidised-bed reactors the fuel is mixed with the bed material and in entrained flow gasifiers the fuel is converted in suspension. Therefore, the product gas contains high amounts of dust and ashes, which have to be separated from the gas before further processing. Furthermore, dust and ashes can cause depositions on walls or heat exchanger tubes and blockage of pipes and valves. Fluidised-bed reactors are typically applied for medium-scale and large-scale systems (above 20 MW fuel power), entrained flow reactors typically only for large-scale systems (above 50 MW fuel power).

[0009] Existing downdraft biomass gasifiers require high quality wood fuels with clearly defined particle sizes and moisture contents and usually cannot be scaled up to economically attractive scales without severely increased tar production. Multi-stage downdraft gasifiers, which comprise separate zones for fuel pyrolysis, partial oxidation, and reduction of product gas, have also been developed. However, such gasifiers also show high dust concentrations in the product gas and are technologically complex.

[0010] For instance, prior art document CZ 295171 discloses a continuous multi-stage vertically sequenced gasification process or method for conversion of solid carbonaceous fuel material into product gas in a gasifier comprising a pyrolysis zone, a partial oxidation zone located vertically downstream of the pyrolysis zone, a reduction zone located vertically downstream of the partial oxidation zone and comprising a downwardly angled perforated floor and a deflector located in the centre of the floor. The gasifier is configured such that the gases released from the drying and the pyrolysis zone can be exhausted and introduced through a bypass into the combined reduction and combustion zone for additional heat-up in order to reduce tars. This gasifier is structurally complicated and difficult to control.

[0011] WO 2017/102945 discloses a system comprising a downdraft fixed-bed gasification reactor for the production of product gas and a quench chamber for receiving the product gas from the reactor. A product gas outlet of the reactor is fluidly connected with the quench chamber via a tubular dip tube. The resulting product gas is almost free of tars but typically has to be heated up again for further processing. Furthermore, the quench water has to be extensively cleaned.

[0012] Updraft gasifiers are usually used for the production of heat as it is described in WO 2010 022 741 A2. The product gases released from the moving bed updraft gasifier are burnt in a gas combustion chamber which is coupled to the gasifier. The hot flue gas can be used for several purposes, e.g. for production of steam, hot water or hot oils. "The Heuristic Envirocycler, a Solid Waste Disposal Energy Recovery Device for the 1990's, Lefcort M.D.; In: Bridgwater A.V. (eds) Advances in Ther-

mochemical Biomass Conversion, Springer Science + Business Media Dordrecht" discloses a combustion technology consisting of an updraft gasifier which is directly coupled to a gas combustion chamber where the product gas released from the gasifier is burnt. The hot flue gases are cooled in a water boiler located downstream the combustion chamber for heat production.

[0013] FI 100 033 B discloses a system, which consists of an updraft fixed-bed gasifier where the primary air is supplied under lean air conditions from below the grate acting as gasification air and the fuel is supplied laterally to the top section of the fuel bed which is formed on the inclined grate. A part of the combustion air (secondary air) is supplied directly above the fuel bed, initiates the combustion of the gas and the resulting radiation is partly transferred to the top layer of the fuel bed. The remaining combustion air (tertiary air) is supplied into the gas combustion chamber, which is directly coupled to the gasifier and where the product gas undergoes complete combustion.

[0014] In the past updraft gasifiers have been used for automotive engines. Lately, updraft gasifiers are also used for the production of electricity as it is described in WO 2008 004 070 A1. This patent comprises an updraft fixed-bed gasifier and a gas engine driving an electrical generator for producing electrical power. The gas engine is being driven by the product gas produced by the gasifier. Before entering the gas engine, the product gas is cooled and has to be extensively cleaned.

[0015] Updraft gasifiers show a simple feeding and transporting mechanism, both into the reactor and out of the reactor. The fuel is fed from above and the ashes are discharged at the lower end of the gasification reactor. It is well known that updraft gasifiers convert the fuel very well and that the ashes usually show a good burnout quality (carbon content < 5 wt.% d.b. (i.e. weight percent)). Updraft gasification technology is known as a simple, fuel flexible and robust technology. However, the updraft gasification technology has some disadvantages such as:

- The product gas has a high content of tars and other unburned hydrocarbons, which are difficult to clean when product gas production is the aim of the gasification process
- Scaling-up is typically limited to about 20 MW in order to ensure good mixing conditions in the gasification reactor and due to mechanical constraints

[0016] Nevertheless, it is well known that the product gas of an updraft gasifier shows significantly lower contents of particles compared to downdraft gasifiers or fluidised-bed or entrained flow gasifiers due to the low gas velocities at bed exit and the "filtering effects" of the bed which is of great advantage in terms of fouling and particle depositions in all units downstream the gasification reactor.

[0017] *"Tars are the Achilles heel of gasifiers, and many gasifier projects have failed because of insufficient attention to low tar production or efficient tar destruction". "Several different classifications of tar have been established. These classifications are related to temperatures. Classification has been developed as follows: "primary tars" are vapours produced at lower temperatures and are the first evolved in thermal depolymerization of cellulose, hemicellulose, and lignin these are mainly oxygenated compounds. Next, the secondary and tertiary reaction products of primary tars are termed "secondary tar" and "tertiary tar". Tertiary tars were sub-classified as tertiary-alkyl and tertiary-polynuclear aromatic hydrocarbons (PAH). It is hypothesized that once tertiary tars are formed these may require even higher temperatures and additional residence time for thermal decomposition"* - Tom B. Reed (T. Milne 1998)

[0018] Furthermore, tars can be removed from the gas by e.g. a wet scrubber or a wet ESP, but as tars from updraft gasifiers contain energy a removal of tars results in efficiency losses.

[0019] Also, tars can be removed by indirectly heated thermal cracking. This method has been discussed in the open literature to reduce tars in raw product gas. *"In the absence of char, a temperature of 900° C is insufficient to achieve efficient tar destruction. It is a common hypothesis that a minimum temperature of 1,000° C is necessary to achieve an almost complete conversion of the tars"* - (Hauben, M. P. Analysis of tar removal in a partial oxidation burner. PhD thesis; Technical University Eindhoven (Netherlands), 2004, (Morf P.O, Secondary reactions of Tar during Thermochemical Biomass Conversion. PhD thesis; ETH Zürich (Switzerland), 2001.). Concluding, thermal cracking seems not to be a promising approach due to the high required reaction temperatures, and thus, the energy efficiency is low.

[0020] Also, partial oxidation has been explored as an alternative method for achieving tar destruction. DE 60 033 782 T2 discloses a system, which consists of an updraft fixed layer gasifier which is connected to a cracking module via a product gas pipeline. Secondary air is supplied directly above the fuel bed and the cracking organ may be a catalytic or a thermal cracking organ, which may in addition be based on a tertiary air feed. According to this prior art document, the gasification reactor and the partial oxidation unit are separated by the product gas pipeline, which may be a drawback due to possible blockage of the pipe due to tar condensation.

[0021] CA 2 521 982 A discloses a process / method and apparatus for converting coal into a substitute natural gas generating raw gas in a conventional fixed-bed coal gasification unit and passing at least a portion of the raw gas into a partial oxidation unit to convert at least a portion of the raw gas into a secondary raw synthesis gas substantially to avoid higher hydrocarbons in the gas. Optionally, the raw gas is quenched and only the resulting condensate is passed to the partial oxidation unit for conversion to a secondary raw synthesis gas.

[0022] CN 102 911 739 A discloses a system which consists of an updraft fixed-bed gasifier, which is connected to a partial oxidation unit via a product gas pipeline. The method mainly comprises a fixed-bed gasification reactor covered with an insulation made of refractory bricks and a water-cooled jacket and a non-catalytic partial oxidation reactor, which is separated from the gasifier by the product gas pipeline. The gas pipeline may be prone to blocking due to tar condensation.

Pyrolysis reactors for biochar production

[0023] Pyrolysis reactors for biochar production are typically fixed-bed or moving-bed systems where biomass undergoes a thermal treatment without addition of any oxidising medium (stoichiometric air ratio zero or close to zero) and where a rather slow heat-up of the biomass occurs. Typical pyrolysis temperatures (temperature of the biomass / charcoal bed) to produce biochar are in the range of 350 to 600°C and the residence time of the biomass in such reactors typically ranges from 0.5 to 3 h. Pyrolysis reactors can be batch reactors or continuously operating reactors. The products of such reactors are biochar and a pyrolysis gas (product gas). The biochar amounts to typically 20 - 35 wt. % of the dry biomass input, the rest is pyrolysis gas. The pyrolysis gas contains very high tar concentrations and can be used for combustion in special pyrolysis gas burners and may thereby cover the heat demand for the pyrolysis process and may also be used for biomass drying prior to pyrolysis.

[0024] Wood charring in piles has been applied since ancient times. With this outdated process, biochar mass yields of only 20-25 wt. % of the dry input can be gained. As the product gas is released to the ambient, emissions are extremely high.

[0025] DD 238 162 A1 discloses a continuously working method for the production of charcoal where the feed material is supplied from above in a shaft furnace with a rotating grate and oxygen lean process gas derived from an external combustion chamber is supplied at the bottom of the furnace for energy supply. The charcoal leaves the furnace on its bottom and the product gases on its top. The so-called Schottendorf-Meiler represents an industrial application based on this basic principle. Biomass is supplied from above to a cylindrical reactor and is dried and pyrolysed on the way downwards. Partial burning of the biochar in a zone in the lower area of the reactor provides the process heat. An energetic utilization of the product gas leaving from the top of the reactor is not implemented.

[0026] DE 2 953 663 A1 discloses a continuously working method for the production of charcoal from wood, where wood is fed from above in a reactor and then passes through a drying and a pyrolysis zone before being discharged at the bottom of the reactor. Product gas evolving from the pyrolysis zone is led to a combustion chamber, where it is burned with air and the hot flue gas

is led in a cross-flow through the bottom of the charcoal bed, where a part of the charcoal is burned to supply the above pyrolysis process with energy.

[0027] The so-called Reichert retort (Kaltschmitt, M., Hartmann H., Hofbauer H., 2009, "Energie aus Biomasse", Springer-Verlag, Berlin Heidelberg, ISBN: 978-3-540-85094-6.) represents a discontinuous retort process, where the biomass is fed to a retort. The product gas evolving from the process /method is first treated in scrubbers and condensers to remove the tars and is then burnt to provide the energy needed for drying and heating the feedstock.

[0028] US 2020/0270528 A1 discloses a discontinuously working process/method and plant for producing biocoal, in which biogeneous feedstock material is located in retorts and pyrolysed and the flammable pyrolysis gases formed are burned to generate hot flue gases. The retorts are introduced consecutively into at least one reactor chamber and by use of the flue gases the heat for the pyrolysis process is supplied. The retorts are at least largely closed towards entry of hot flue gases and the heating of the starting materials located in the retorts by the flue gasses is effected only indirectly via the heating of the retorts.

[0029] DE 10 2005 045 166 B4 describes a charring process which is based on a twinscrew reactor operated at 500-700°C with residence times of the biomass of 15 to 45 minutes (depending on the feedstock). Due to the intensive bed motions, char particles are entrained with the product gas, which have to be removed in a hot gas dust separator before the PG is burnt in a flameless oxidation burner. The hot exhaust gases are used for reactor heating, feedstock drying and optional for district heat production.

[0030] A continuously operating counter-current pyrolysis reactor with external energy supply and without combustion of charcoal to provide energy to produce biochar which is close-coupled with a pyrolysis gas treatment reactor as described in this patent application is novel.

SUMMARY OF THE INVENTION

[0031] In view of the above described prior art and the above described problem(s), it is thus an object of the invention to reduce the tar content of the gas in such a gas treatment reactor by more than 95% or even up to 99% (in other words: below 5 g tars / Nm³ or preferably below 1 g / Nm³ of final product gas).

[0032] The object of the invention is solved by the method of the independent method claim 1 and the subject-matter of the independent device claim 2.

[0033] According to an aspect of an example embodiment a method to produce a product gas with low tar and dust contents from solid biomass, biogenic residues and/or organic waste fractions with a gas production device is provided, the gas production device comprising: a fuel conversion reactor which is an updraft gasification reactor 1a or a pyrolysis reactor; and a gas treatment

reactor located downstream the fuel conversion reactor; wherein the fuel conversion reactor is close-coupled with the gas treatment reactor; wherein the fuel conversion reactor comprises a space to contain a fuel bed above a grate; wherein the gas treatment reactor comprises the following: a POX zone, and at least one POX nozzle for supplying an oxidiser into the POX zone; and a gas heating zone fluidic located between the space to contain the fuel bed and the POX zone; wherein the method comprises the following steps:

Creating an initial product gas in the fuel conversion reactor;

Heating the initial product gas, which is created in the fuel conversion reactor in the gas heating zone;

[0034] Combusting the heated initial product gas in the gas treatment reactor at least partially in the POX zone of the gas treatment reactor by injecting or supplying an oxidiser through the POX nozzles into the POX zone.

[0035] According to an aspect of an example embodiment a gas production device for producing a product gas with low tar and dust contents from solid biomass, biogenic residues and/or organic waste fractions is provided, the gas production device comprising: a fuel conversion reactor, which is an updraft gasification reactor or a pyrolysis reactor; and a gas treatment reactor located downstream the fuel conversion reactor; wherein the fuel conversion reactor is close-coupled with the gas treatment reactor; wherein the fuel conversion reactor comprises a space to contain a fuel bed above a grate; wherein the gas treatment reactor comprises the following: a POX zone, and at least one POX nozzle for supplying an oxidiser into the POX zone; and a gas heating zone fluidic located between the space to contain the fuel bed and the POX zone; wherein the gas production device is configured such that: an initial product gas is created in the fuel conversion reactor; and the initial product gas, which is created in the fuel conversion reactor is heated in the gas heating zone; and the heated initial product gas in the gas treatment reactor is combusted at least partially in the POX zone of the gas treatment reactor by injecting or supplying an oxidiser through least one POX nozzle into the POX zone.

[0036] According to a modification of above aspects a method or a device is provided, wherein the chemical/physical processes in the gas production device 100 are configured such that the tar content of a final product gas V downstream the gas treatment reactor 2 and after the POX zone 12 is below 5 wt% (percent of weight) of the tar content of the initial product gas upstream the gas treatment reactor 2.

[0037] According to a modification of above aspects a method or a device is provided, wherein least one POX nozzle 22 is positioned at a distance to the grate 4 such that the flow of gases, which is induced by the oxidiser,

does not disturb the fuel bed; and/or that the surface temperature of the fuel bed 3 is kept below 450°C.

[0038] According to a modification of above aspects a method or a device is provided, wherein the residence time of the product gas in the gas treatment reactor 2 is above 0.2 seconds, and preferably below 1 minute or even more preferably below 10 seconds, and/or a stoichiometric air ratio of the gas treatment reactor 2 is between 0.25 and 0.6, and preferably between 0.35 and 0.5.

[0039] According to a modification of above aspects a method or a device is provided, wherein the gas treatment reactor 2 is located above the fuel conversion reactor 1a, 1b in a height direction; and/or wherein the gas treatment reactor 2 is arranged laterally or angular to the fuel conversion reactor 1a, 1b.

[0040] According to a modification of above aspects a method or a device is provided, wherein a tar and soot reforming catalyst is provided before or after the POX zone 12 to further improve tar and soot reforming.

[0041] A catalytic cracking can be performed using mineral catalysts or a reforming can be performed with metal catalysts.

[0042] One advantage of catalytic tar cracking is that it does not reduce the heating value of the gas, as would be the case if the tars were thermally cracked at a high temperature. In catalytic cracking, the catalyst (typically a monolith, a wire mesh or a packed bed) may be used either in-situ in the gasification reactor or in a separate reactor downstream of the gasifier. There is a large number of different catalysts that have been used to reduce the tar contents in product gases from gasification processes. The two most researched groups are Ni-based catalysts as well as dolomite and olivine. *"The operating temperature of the catalyst depends of the catalyst used and is typically in the range of 750 to 950 °C."*-(Fjellerup, J., Ahrenfeldt, J., Henriksen, U., & Gøbel, B. (2005). Formation, Decomposition and Cracking of Biomass Tars in Gasification. Kgs.Lyngby: Technical University of Denmark. Department of Mechanical Engineering.)

[0043] According to a modification of above aspects a method or a device is provided, wherein the stages of the updraft gasification reactor 1a comprise: a drying and pyrolysis zone 5 in the upper part of the fuel bed, in which the solid fuel is dried and pyrolysed without the addition of oxygen; a gasification zone 6 located below the pyrolysis stage; and an oxidation zone 7 located at the bottom of the fuel bed, in which the solid charcoal is converted to ashes and gases; wherein the drying and pyrolysis, the gasification and the oxidation stages are formed over the height of the gasification reactor 1a.

[0044] According to a modification of above aspects a method or a device is provided, wherein the pyrolysis reactor 1b comprises a drying zone 5 and a subsequent pyrolysis zone 6 in the fuel bed 3; wherein the fuel and the product gas move in a counter-current direction to each other; and/or wherein the pyrolysis reactor 1b is externally heated or heated by a hot inert gas passing

through the pyrolysis reactor 1b.

[0045] According to a modification of above aspects a method or a device is provided, wherein the oxidiser injected into the gas treatment reactor 2 is air or oxygen or an air/steam mixture or a mixture of these gases.

[0046] According to a modification of above aspects a method or a device is provided, wherein the method additionally comprises the step of preheating the oxidiser or the device is additionally configured to preheat the oxidiser by preheating means.

[0047] According to a modification of above aspects a method or a device is provided, wherein the oxidiser injected into the gas treatment reactor 2 is pre-heated by the reaction in the POX zone 12 or by pre-heating means 11.

[0048] According to a modification of above aspects a method or a device is provided, wherein the gas treatment reactor 2 is, preferably fully, insulated in order to minimise heat losses.

[0049] According to a modification of above aspects a method or a device is provided, wherein a temperature in the oxidation zone 7 of a gasification reactor 1a is controlled by the addition of steam or flue gas or a mixture of these gases such that the temperature is between 800°C and 1100°C, preferably between 800°C and 999°C.

[0050] According to a modification of above aspects a method or a device is provided, wherein at least a part of the fuel bed 3 close to the bottom of the pyrolysis reactor 1b is above 450°C by controlling a temperature of a gas used to heat the pyrolysis reactor externally.

[0051] According to a modification of above aspects a method or a device is provided, wherein the POX zone 12 of the gas treatment reactor 2 has or reaches a temperature of more than 800°C, preferably more than 1000°C, even more preferably a temperature between 1000°C and 1100°C.

[0052] To summarize the above, a method and a device of the invention can comprise a, preferably continuously operating (i.e. not operating in interval), fuel conversion reactor comprising an updraft fixed-bed or a moving-bed gasification reactor or a pyrolysis reactor and a close-coupled gas treatment reactor for gas and tar reforming of the product gas by means of partial oxidation (POX) or a combination of external heating by a heat carrier and POX. In the conversion reactor the solid fuel can be converted into combustible gases and the remaining solids (ashes and charcoal).

[0053] The gases released from the top of the conversion reactor, which contain low particle concentrations but a considerable amount of tars (typically 50 - 2000 g / Nm³) then get first thermally treated and, after the thermal treatment, partially combusted in the gas treatment reactor, which is preferably located above the conversion reactor or located laterally or angular to the conversion reactor.

[0054] As an advantageous consequence, the treated product gas can then be handled more easily in down-

stream processes (e.g. subsequent gas cleaning steps or gas utilisation units like engines, turbines, fuel cells or gas combustion devices).

[0055] According to an aspect of an example embodiment, the present invention can comprise a method or a device for the production of a product gas with a low tar and dust content from fuel, for example solid biomass fuels, biogenic residues or organic waste fractions with a gas production device. Hence, the fuel can preferably be biogenic fuel or biological fuel, e.g. wood chips or wood pellets.

[0056] The disclosure provides a gas production device, which comprises a combination of a fixed or moving-bed updraft gasification or pyrolysis system (in the following both is referred to as fuel conversion reactor) coupled with a gas treatment reactor, which contains at least one partial oxidation zone and at least one gas heating zone in order to produce a (final) product gas with a low particle and tar content.

[0057] Preferably and optionally, the fuel conversion reactor (i.e. an updraft gasification reactor or a pyrolysis reactor) can be advantageously provided close-coupled with the gas treatment reactor for high efficiency and favourable manufacturing costs of the gas production device.

[0058] The fuel conversion reactor converts the fuel, which is supplied into the fuel conversion reactor, into an initial product gas, which usually has a low particle but a high tar content.

[0059] The gas treatment reactor treats the initial product gas such that the particle content is kept low and the tar content of the product gas is considerably lowered and a final product gas is created, which is the output of the gas production device.

[0060] The gas treatment reactor contains at least one gas heating zone and at least one partial oxidation zone (in short: "POX zone") in order to produce the final product gas with a low particle and tar content.

[0061] The fuel conversion reactor is therefore located upstream of the gas treatment reactor. The gas heating zone of the gas treatment reactor is located downstream the fuel conversion reactor and upstream the POX zone of the gas treatment reactor. Hence, the POX zone is located downstream the gas heating zone and downstream the fuel conversion reactor.

[0062] The gas heating zone of the gas treatment reactor is for (at least partially) heating the initial product gas up to a predefined temperature.

[0063] The POX zone is for providing a partial oxidation of the heated initial product gas. The partial oxidation (in short: "POX") can be achieved by injecting an oxidising agent/oxidiser, i.e. an oxygen carrier into the gas (air, oxygen, an air/steam mixture or mixtures of these gases). Moreover, these oxidisers may also be pre-heated in order to reduce the amount needed to achieve a certain target temperature in the POX reactor. Furthermore, the product gas is heated before it enters the POX zone by external heating in a heat exchanger (e.g. by hot flue

gas) or by radiation from the POX zone towards the fuel bed or by both options. Optional external heating of the product gas before entering the POX zone can reduce the amount of oxidiser needed to achieve a certain target temperature in the POX reactor.

[0064] Furthermore, the fuel, e.g. solid carbonaceous biomass, is fed into the upper region of the fuel bed or on top of the fuel bed of the fuel conversion reactor, which is usually a cylindrical or rectangular reactor, and forms a packed bed on the grate. The height of the fuel bed inside the gasifier, respectively pyrolyser, can be preferably held almost constant by means of a mechanical level control or sensors based on radar or ultrasonic sound or even mechanical means.

[0065] The fuel can preferably be fed into the fuel bed from below the maximum height of the fuel bed. I.e. the solid carbonaceous biomass cannot be introduced into the reactor such that it falls down onto the upper surface of the reactor bed, but such that it is introduced into the fuel bed (e.g. from sideways). Hence, the supplied fuel can preferably be supplied such that it is pressed into the fuel bed.

[0066] As a further advantageous consequence, the surface of the fuel bed is more level /more flat, and as a consequence to this, the particles of the fuel bed are not churned and disadvantageously carried away by the flow of the product gas. Additionally, the zones of pyrolysis and drying are mixed up by the above described special manner of supply of the fuel, and thus the efficiency (and fuel usage) of the reactor is increased, since "dead zones" for the fuel reaction are avoided.

[0067] In case of an updraft gasifier as fuel conversion reactor, the gasification agent, dry or humidified air or oxygen or recirculated flue gas or mixtures of these gases, is injected from the bottom below the grate or in the region of the grate, passes through the fuel bed and hot product gas exits the gasifier at the top of the fuel bed at around 80 to 450 °C (the exit temperature depends mainly on the moisture content of the fuel).

[0068] Preferably, the fuel conversion reactor is controlled such that the temperature of the ash on the grate is above 300°C, such that no ash layer is formed above the grate (i.e. only a char oxidation layer is created). Experiments and simulations resulted in the conclusion that temperatures of above 300°C onto the grate improve the overall performance of the herein described method and device. In detail, this minimum temperature of above 300°C advantageously (mostly) avoids the release of ash formers. A long ash residence time on the grate (which is the case when temperature of below 300°C exist on the grate) typically increases K release and thus dust emissions; Hence, with the minimum temperature of above 300°C on the grate, the ash residence time on the grate is therefore kept short and hence also the temperature of the ash is clearly above 300°C.

[0069] The overall gasification process in the updraft gasifier can, on one hand, be seen as separated into several different reaction zones, stratified along the re-

actor height, wherein drying and pyrolysis often go on in parallel due to rapid heating of the particle surface (although the separation is not mandatory). On the other hand, the reaction zones can be seen as combined reaction zones (see Fig. 5).

[0070] At the top of the bed the fuel is heated and dried by the hot product gas passing through the fuel bed as well as by radiation, convection and conduction from the gas treatment reactor. At particle (bed) temperatures of about more than 200 °C, pyrolysis of the fuel takes place and solid char particles and volatiles are formed. The char particles move downwards, heat up and get reduced by hot gases as gasification processes start at approximately more than 600 °C. The char is partially converted into product gas mainly by endothermic reactions.

[0071] Finally, the remaining char is burnt by the supplied gasification agent (dry or humidified air or oxygen or recirculated flue gas or mixtures of these gases) in the oxidizing zone located at the bottom of the gasifier, supplying heat for the overlying processes. The fuel ashes fall through the grate or drop down at the end of the grate and get discharged by means of an ashes removal system, e.g. by means of a conveying screw. The de-ashing process/method can be controlled in dependence of the ashes' temperature or time-dependently.

[0072] Due to char oxidation, the solid (bed) temperature attains high values above the grate, usually between 800 and 1,100 °C. The temperature in the oxidizing zone is usually controlled by the addition of steam or flue gas or a mixture of these gases (in order to avoid ash melting or ash sintering on the grate).

[0073] The initial product gas from the updraft gasification reactor consists of CO, H₂, CO₂, CH₄, water vapour, N₂, high amounts of tars and certain amounts of higher hydrocarbons, such as ethane and propane, as well as organic acids.

[0074] In case of a fixed or moving-bed updraft pyrolyser as fuel conversion reactor, no oxidation agent is injected into the reactor. The fuel bed is heated up by e.g. indirect heating through the reactor walls by e.g. hot flue gases or electric heaters or by direct heating by the injection of a pre-heated inert gas at the bottom of the pyrolyser. The fuel bed is pyrolysed and the hot product gas produced passes through the fuel bed upwards and dries the fresh fuel. The char particles formed move downwards and get further heated. At the bottom of the reactor the charcoal falls through the grate or drops down at the end of the grate and gets discharged by means of a charcoal removal system, e.g. by means of a conveying screw. By controlling the charcoal discharge, the residence time of the biomass in the reactor and thus the carbonisation degree can be controlled. The temperature of the charcoal (target pyrolysis temperature) is controlled by the temperature of the heated reactor walls or of the pre-heated inert gas.

[0075] Not considering a possibly present inert gas, the initial product gas from the pyrolysis reactor consists of CO, H₂, CO₂, CH₄, water vapour, high amounts of tars

and certain amounts of higher hydrocarbons, such as ethane and propane, as well as organic acids.

[0076] The high tar contents and high dust contents of product gasses from fuel conversion reactors are a main problem of conventional fuel conversion reactors. To solve these problems, the invention (inter alia) provides the combination of an updraft fuel conversion reactor with a gas treatment reactor as described herein.

[0077] Preferably, the gas treatment reactor can be close-coupled with the fuel conversion reactor and can be preferably located right above (vertical) the fuel conversion reactor or laterally or angular to the fuel conversion reactor. The gas treatment reactor is preferably partially or even fully insulated in order to prevent tar condensation and heat losses.

[0078] In the gas heating zone, i.e. in the first section of this gas treatment reactor, the product gas is heated by direct or indirect energy input. The product gas can be heated by radiation, conduction and convection induced from the partial oxidation zone, but it can also be heated in a heat exchanger, where heat is transferred to the product gas indirectly (e.g. by hot flue gas). The height or length of this first section mainly depends on whether external heating is applied or not - if external heating is applied then it depends mainly on the dimensions of the heat exchanger, if no external heating is applied a certain spacing between the fuel bed surface and POX nozzles (explained later) needs to be considered in order to avoid a flow that hits the fuel bed induced by the POX nozzles (as this would cause particle entrainment) and also to avoid too high bed surface temperatures - they should not exceed 450°C in order not to disturb the ash-filtering effect caused by the fuel bed.

[0079] The (pre-)heated (initial) product gas is then introduced into the partial oxidation zone, i.e. into the second section of the gas treatment reactor, and is reformed by means of partial oxidation in the presence of an oxidizing agent in order to reform the initial product gas towards low tar levels, achieving typically a reduction of more than 95% related to the tar content of the product gas at fuel bed exit. The oxidizing agent / oxidiser is introduced into the POX zone by means of at least one POX nozzle.

[0080] The result of the reformation of the initial product gas with high tar and dust content is a final product gas of the gas production device with a low dust and tar content.

[0081] It is to be noted, that more than 4, preferably more than 6 POX nozzles can be preferably used such that a better distribution of the oxidiser can be realized in the POX zone for a more homogenous and efficient reaction.

[0082] The POX nozzles can be either integrated into the wall of the gas treatment reactor at the POX zone, or the POX nozzles can be provided by injection lances (tubes with nozzles), which are arranged in the POX zone and which can partially or fully pass through the inner volume of the POX zone of the gas treatment reactor.

Further, the supply passages (e.g. a main supply passage or tubing and distribution passages or tubings to the nozzles or lances with nozzles) to the nozzles can preferably be integrated into the wall of the gas treatment reactor.

[0083] In both above mentioned configurations, the reaction in the POX zone heats up the nozzles and/or lances and the wall of the gas treatment reactor, and thus the oxidiser can be advantageously pre-heated before entering the POX zone. Consequently, the reaction in the POX zone is more efficient (ignition delays can be minimised) and a better mixing between oxidiser and gas can be achieved.

[0084] Preferably, the oxidizer can enter into the POX zone through a central supply (passage) and can flow through a distribution channel, which is integrated in the reactor, to the POX nozzles/lances. It is to be noted that in the case of lances with nozzles, the oxidizer is advantageously even more preheated before entering the POX zone as compared to nozzles, which are integrated into the walls of the gas treatment reactor.

[0085] The temperature in the POX zone is preferably (at least partially or fully) above 800°C for a good efficiency.

[0086] Even more preferably, a temperature in the POX zone is (at least partially or fully) above 1000°C in order to crack the tars in the product gas most efficiently and to reach the defined rates of tar reduction.

[0087] It has taken a considerable amount of experiments / measurements and CFD-simulations in order to find this minimum temperature of 1000°C in the POX zone as the optimal minimal temperature, which is suitable to reach the above defined reduction rates of the tar, which are in practice very low as compared to prior art, and is additionally not too high in order to provide the POX with a high efficiency.

[0088] It is to be noted that the "temperature in the POX zone" of above 1000°C can relate to the zone as whole, or only to parts of the zone. In this context, it is to be noted that the temperature naturally decreases after the nozzles for injecting the oxidiser, since the main place of reaction in the POX zone is where the nozzles are located and because after oxidation reactions close to the POX nozzles occur endothermic gasification reactions prevail. This can be seen also in the temperature graph in Fig. 2.

[0089] Furthermore, a temperature in the POX zone can be above 1000°C and below 1100°C as an optimum for the tar reduction and the energy efficiency (and the supply amount of oxidiser) of the POX zone for updraft gasifiers and up to 1,400°C for updraft pyrolysers as the gas from updraft pyrolysis reactors contains considerably higher amounts of tars in comparison to updraft gasification reactors.

[0090] The oxidiser injected into the POX zone can be preferably pre-heated to temperatures of above 150°C (by temperature pre-heating means), before the oxidiser is injected into the POX zone (before the oxidiser is reaching the POX zone).

[0091] The gas heating zone is fluidic (i.e. in view of the flow of the process gas) located between the space (i.e. the inner room of the updraft gasification reactor or pyrolysis reactor for containing the fuel bed and the corresponding reactions) and the POX zone.

[0092] The stoichiometric air ratio in the POX reactor (= (oxygen supplied to the POX reactor + in case of a gasifier oxygen supplied to the gasifier) / oxygen needed for a complete stoichiometric conversion of the fuel) is typically between 0.25 and 0.6 (depending on the gas temperature at POX zone inlet and the temperature of the oxidiser upstream the POX zone and also on the fact whether an updraft gasifier or an updraft pyrolyser are applied). The POX zone needs to be well insulated to minimise heat losses.

[0093] The amount of oxidizing agent supplied, and therefore the stoichiometric air ratio of the POX zone are controlled in dependence of the product gas temperature measured by at least one temperature sensor, e.g. a thermocouple, located in the POX zone. Hence, controlling means can be provided for controlling the product gas temperature and the stoichiometric ratio in the POX zone. In general, controlling means can be provided to control the main parameters of the processes in the gas production device, such as the flows of the oxidiser and fuel into the gas production device as well as temperatures in the gas production device and the level of the fuel bed.

[0094] The oxidizing agent can be injected into the POX reactor at one or at different positions. The oxidizing agent is air or oxygen or an air/steam mixture or a mixture of these gases; they can be injected combined or separately. The oxidizing agent can be supplied at ambient temperature or pre-heated a) electrically and/or b) thermally (e.g. by hot gas in a heat exchanger).

[0095] The injection nozzles preferably ensure a good mixing of the oxidiser with the gas in the POX zone in order to avoid strain formation. This could be achieved e.g. by appropriately designed injection lances or by inducing a swirling flow in the POX zone. Moreover, the injection nozzles can be placed in a uniform height in the POX zone or at different positions / heights.

[0096] The residence time of the gas in the POX zone is preferably at least 0.2 seconds but may also be more than 1 second for high efficiency. Hence, the geometry of the POX zone and the amount of initial product gas created can preferably be configured in such a way that the flow velocity of the product gas is low enough in order to not pass the POX zone in less than 0.2 seconds.

[0097] The fuel conversion reactor is preferably round or rectangular in its inner cross-sectional profile, i.e. has an oval or round or rectangular inner diameter as to be seen in its cross section perpendicular to a length direction of the reactor. The solid fuel bed as well as the gas treatment reactor may have the same or different diameters. For instance, the fuel conversion reactor may have one diameter and above in the gas treatment reactor, the reactor may be smaller or wider.

[0098] The stoichiometric air ratio in the sense of this

application is calculated as follows: (oxygen supplied in the counter-current reactor and in the POX zone of the gas treatment reactor) / oxygen needed for a complete stoichiometric combustion of the fuel. The respective amounts can be either calculated per volume [m³] or per weight [kilogram or gramm].

[0099] The gas treatment reactor is preferably located above the fuel conversion reactor or laterally or angular to the fuel conversion reactor.

[0100] The term "close-coupled" in the sense of this application can be understood as "directly connected" and/or as "a maximum distance of two features of 3 meters, preferably of 1 meter" and/or such that there is an effective thermal coupling of the two "close-coupled" features.

[0101] In a functional sense the "close-coupling" of the fuel conversion reactor and the gas treatment reactor is preferably such close that the heat from the gas heating zone can be used as additional energy input for the fuel conversion reactor. In other words, the fuel conversion reactor and the gas treatment reactor are coupled such that thermal energy from the gas heating zone of the gas treatment reactor can act on the fuel in the fuel conversion reactor, e.g. improve drying and pyrolysis/gasification.

[0102] An "oxidiser" in the sense of this application can preferably be air, oxygen, an air/steam mixture or mixtures of these gases

BRIEF DESCRIPTION OF THE DRAWINGS

[0103] The invention is herein described, by way of example only, with reference to the accompanying drawings. With specific reference to the drawings in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and are presented in order to provide what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

[0104] The above and other objects and features will become more apparent from the following description of example embodiments with reference to the accompanying drawings in which:

Fig. 1 shows a sectional view of an exemplary embodiment of the gas production device (method/device), wherein the gas treatment reactor is coupled with an updraft gasification reactor;

Fig. 2 shows the embodiment of Fig.1 including locations of temperature measurements and a temperature graph over the length direction of the

gas production device;

Fig. 3 shows a sectional view of a modification of the embodiment of the gas production device (method/device), wherein the gas treatment reactor is located laterally to and above an updraft gasification reactor;

Fig. 4 shows a sectional view of a further modification of the embodiment of the gas production device where the gas treatment reactor is coupled with an updraft pyrolysis reactor.

Fig. 5 shows a sectional view the embodiment of Fig. 1, wherein the zones inside the updraft gasification reactor of Fig. 5 are placed differently as compared to Fig. 1.

DETAILED DESCRIPTION OF THE INVENTION

[0105] Various embodiments of the present disclosure are disclosed below with reference to the accompanying drawings. However, embodiments and terms used therein are not intended to limit the present disclosure to particular embodiments and should be construed to include various modifications, equivalents and/or alternatives in accordance with embodiments of the present disclosure.

[0106] Should more general terms be used in the description for features or elements shown in the figures, it is intended that not only is the specific feature or element disclosed in the figures for those skilled in the art, but also the more general technical teachings.

[0107] With respect to the description of the figures, the same reference signs may be used in the individual figures to refer to similar or technically corresponding elements. Further, for the sake of clarity, more elements or features may be shown with reference signs in individual detail or section views than in the overview views. It is to be assumed that these elements or features are also disclosed accordingly in the different figures, even if they are not explicitly listed there.

[0108] It is to be understood that a singular form of a noun corresponding to an object may include one or more of the things, unless the relevant context clearly indicates otherwise.

[0109] In the present disclosure, an expression such as "A or B", "at least one of A or/and B", or "one or more of A or/and B" may include all possible combinations of features listed together. Expressions such as "first," "second," "primary," or "secondary" used herein may represent different elements regardless of their order and/or meaning and do not limit corresponding elements. When it is described that an element (e.g., a first element) is "operatively" or "communicatively" coupled or connected to another element (e.g., a second element), the element may be directly connected to the other element or connected to the other element via another element (e.g., a third element).

[0110] For example, an expression "configured to" (or "arranged to") used in the present disclosure may be replaced with "suitable for," "adapted to," "made to," "capable of," or "designed to," depending on what is technically possible. Alternatively, in a particular situation, an expression "device configured to" or "set up to" may mean that the device is capable of operating in conjunction with another device or component, or performing a corresponding function.

[0111] All size indications, which are given in "mm", are to be understood as a size range of ± 1 mm around the indicated value, unless another tolerance or other ranges are explicitly indicated.

[0112] It should be noted that the present individual aspects, for example the reactors, are disclosed separately as individual parts or individual devices. Thus, it is apparent to one skilled in the art that individual aspects or parts of the system are also disclosed herein on their own independently to the corresponding embodiment. Presently, the individual aspects or system parts are disclosed particularly in the subsections as indicated. It is intended that these individual aspects may also be claimed separately.

[0113] Further, for the sake of clarity, not all features and elements are individually designated in the figures, particularly when they are repeated. Rather, the elements and features are each designated by way of example. Analogous or identical elements are then to be understood as such and in an analogous manner.

[0114] The disclosed embodiment and its modifications, discussed in more detail afterwards, are suitable for gasification systems that include an updraft fixed or moving bed gasification reactor for producing combustible gases with low particulate matter and high tar contents and a close-coupled gas treatment reactor (POX reactor) for heating and partially oxidising the combustible gases to produce a product gas with a low tar content.

Embodiment

[0115] An exemplary embodiment, which is shown in Fig. 1 and in further detail in Fig. 2, comprises a gas production device 100 that combines an updraft gasification reactor 1a (in short: updraft gasifier) and a gas treatment reactor 2.

[0116] In detail, Fig. 1 shows a sectional view of an exemplary embodiment of a gas production device 100 comprising a gas treatment reactor 2 and an updraft gasification reactor 1a located vertically below the gas treatment reactor 2. The gas treatment reactor 2 is placed on top of the updraft gasification reactor 1a. The gas treatment reactor 2 and the updraft gasification reactor 1a can preferably be coupled via a passage 13. The passage 13 can either be a seamless transition between two volumes in one big contained environment or a passage via a tube or via welded parts.

[0117] As to be seen from Fig. 1, the gas treatment reactor 2 and the updraft gasification reactor 1a are close-

coupled in order to allow a (direct) flow from the gas, which results from the updraft gasification, into the gas treatment reactor 2 (c.f. arrow "VI").

[0118] Fuel (as depicted by the arrow "I") is fed into the upper region of a fuel bed 3 of the gasification reactor, which is preferably a cylindrical or rectangular reactor, and preferably forms a packed-bed on a grate 4.

[0119] The height of the gasification reactor 1a is preferably high enough to establish distinguishable zones within the reactor, such that a fuel drying and pyrolysis 5, gasification reactions 6 and charcoal oxidation 7 happen (it is to be noted that the reference numerals 5, 6 and 7 refer to the respective zones / stages and to the respective physical/chemical method steps). Preferably, the height of the gasification reactor 1a is about 1-2 times the diameter. Hence, in order to form these zones/stages, a height of the fuel bed can be higher than 1-2 times the diameter of the fuel bed.

[0120] It is to be noted that the fuel and oxidiser as well as product gas mostly travel in counter-current direction.

[0121] The free (inner) surface above the gasification reactor is preferably designed in a way that the gas velocity right above the fuel bed is preferably below 0.3 m / s in order to minimise particle entrainment.

[0122] The height of the fuel bed 3 inside the gasification reactor 1a is preferably held almost constant by means of a mechanical or electronical level control. For the measurement of the height of the fuel bed 3 inside the gasification reactor 1a, at least one sensor 8 based on radar or ultrasonic sound or a mechanical level control can be used. The measured height of the fuel bed can then be used to e.g. control the amount of the fuel fed into the reactor 1a. The fuel can be fed (c.f. arrow "I") into the reactor 1a by means of a typical fuel feeder.

[0123] A gasification agent, dry or humidified air, oxygen or recirculated flue gas or a mixture of these gases, is injected at the bottom of the gasification reactor (c.f. the arrow "II" in Fig. 1), passes through the fuel bed, and hot product gases exit the gasification reactor at the top at 80 to 450 °C (the temperature depending mainly on the moisture content of the fuel), as depicted by the arrow "VI" in Fig. 1.

[0124] The overall gasification process/method can be separated into three different reaction zones stratified along the reactor height as described above.

[0125] The remaining char at the bottom of the gasification reactor is burnt by the supplied gasification agent (c.f. "II") in the oxidizing zone 7 located close to a grate 4. The fuel ashes drop down the grate as indicated by the arrow "III" in Fig. 1. The grate can optionally be water-cooled.

[0126] The ashes can be discharged by means of an ash-removal system 9, e.g. by means of a conveying screw. The de-ashing process can be controlled in dependence of the ash temperature or time-dependently. If a temperature sensor for controlling the de-ashing process is used, it is preferably placed in the bottom near area of the gasification reactor above the grate (see also

Fig. 2, "T1").

[0127] Fig. 2 shows the gas production device 100 of Fig. 1 including a temperature profile of the gasification device 100. The temperature profile of Fig. 2 shows mere examples of possible temperatures at respective (horizontally aligned) different positions of the gas production device 100. In Fig. 2, the temperature profile refers to the temperatures in the gasification device 100 throughout the height direction of the gasification device 100.

[0128] Due to char combustion, the solid temperature attains high values above the grate, usually between 800 and 1,100 °C. The temperature in the oxidizing zone 7 is controlled by the addition of steam or recirculated flue gas or a mixture of these gases to the gasification agent (e.g. air). This can be done by a defined load-dependent dosing of these gases or based on a temperature control. If a temperature control is used, the temperature sensor is preferably placed in the bottom (near) area of the gasification reactor above the grate (see Fig. 2, "T2"). It is to be noted that the temperature sensors "T1" and "T2" can also be realized as one single sensor (e.g. a PT 100 or PT 1000 sensor). The temperature sensors T1 and T2 can be located in the wall of the reactor 1a, 1b or in the fuel bed 3 itself. Preferably, one temperature sensor "T1" is located in the wall of the reactor and one temperature sensor "T2" is located in the fuel bed 3 of the reactor 1a, 1b. Hence, the temperatures of the fuel bed can be calculated in a more accurate way and controlling the reactions within the reactor 1a, 1b can take into account that the fuel bed 3 has a certain range of its temperature.

[0129] The walls of the updraft gasification reactor 1a can be built of heat-resistant materials such as refractory bricks, fire clay or heat-resistant steel and can optionally be provided fully or at least partially insulated.

[0130] The gas treatment reactor 2 is located preferably vertically above the gasification reactor or laterally or angular to the gasification reactor. The gas treatment reactor can also be optionally provided well insulated in order to prevent tar condensation and heat losses.

[0131] In a heating section 10 / gas heating zone 10 of the gas treatment reactor 2, the product gas is heated by direct or indirect energy input or both. The product gas can either be heated by radiation, conduction and convection induced by the above partial oxidation zone or it can be heated in a heat exchanger section (e.g. hot flue gas circulating around the inner reactor walls as schematically depicted by an inner walls heating means 11 as an example, where heat is transferred to the product gas from e.g. hot flue gas) or by a combination of both options. The heating of the product gas can already induce a gas reforming process/method.

[0132] As to be seen from the temperature profile from Fig. 2, the inner energy of the initial product gas rises (significantly) in the gas heating zone 10, i.e., the temperature rises from below approx.400°C to above approx.550°C. Hence, the gas heating zone 10 (pre) heats the initial product gas by at least 100°C, preferably

150°C, preferably even more than 200°C. Thus, the POX zone 12 can perform its reactions more efficiently. Furthermore, the presence of the gas heating zone 12 creates a distance between the grate 4 and the POX zone 12 with its very high temperatures of preferably above 1000°C. Hence, the effect of the POX zone 12 on the fuel bed surface (heating up the bed surface) can be advantageously limited.

[0133] The pre-heated product gas is then introduced into the partial oxidation zone 12 (in short: POX zone 12) of the gas treatment reactor 2 and is reformed by means of partial oxidation in the presence of an oxidizing agent / oxidizer (the supply of which is indicated by the arrows "IV"). The oxidizing agent / oxidizer is supplied via POX nozzles 22 into the POX zone 12 in order to form a final product gas (the flow of which is indicated by the arrow "V" in Fig. 1) advantageously containing significantly reduced tar levels (5 wt % (percent in weight) or less of the tar content of the product gas upstream the gas treatment reactor). In the partial oxidation zone 12 a partial oxidation of the product gas is performed.

[0134] The oxidiser is injected into the gas treatment reactor 2 at one position or at least two different positions of the at least one POX nozzles 22.

[0135] As to be seen from the temperature profile of Fig. 2, the partial oxidation again rises the inner energy of the preheated product gas as the temperature rises from approx. 600°C to above 1000°C.

[0136] In this embodiment an initial product gas (c.f. arrow "VI") upstream the gas treatment reactor 2) is directly resulting from the gasification in the updraft gasification reactor 1a or from the pyrolysis in the pyrolysis reactor 1b.

[0137] The initial product gas is preferably flowing upstream the gas treatment reactor 2 or, more preferably, at an exit of the fuel bed (3). The final product gas is the product gas at the exit of the gas production device 100, i.e. downstream the POX zone 12. The heated initial product gas is the product gas downstream the gas heating zone 10 and upstream (and in) the POX zone 12.

[0138] The POX nozzles 22 are preferably positioned at a height above the fuel bed 3 or the grate 4 such that the induced flow by the oxidiser does not disturb the fuel bed, i.e. streamlines of the flow of the oxidiser injected do not reach the fuel bed. This can be simulated e.g. by a CFD simulation or measured/checked with a test sample of the device 100. The POX zone 12 usually begins at the start of the reaction of the heated initial product gas with the oxidiser, and thus usually at the position of the POX nozzles 22 (or a bit before these nozzles 22, since the flow of the oxidiser expands a bit after the POX nozzles 12 into the gas treatment reactor 2).

[0139] The temperature in the POX zone 12 is preferably above 800°C, more preferably above 1000°C and even more preferably between 1000°C and 1100°C if coupled with an updraft gasification reactor or even more preferably between 1,000 and 1,400°C if coupled with an updraft pyrolysis reactor in order to achieve a highly ef-

ficient tar reduction. This temperature can be measured by a temperature sensor located in the upper part of the POX zone 12 (where rather uniform temperature conditions prevail, see Fig. 2, "T3"). The measured temperature can serve as an input for a temperature controlling means (e.g. a microcomputer or a controller), which uses e.g. a PID-controlling mechanism. By the temperature controlling means, the temperature in the POX zone 12 can be adjusted by the setting amount of oxidiser supplied into the POX zone 12 (e.g. via at least one valve, which is controlled by the output of the temperature controlling means). The oxidiser may be air or oxygen or an air/steam mixture or a mixture of these gases and it can be injected at ambient temperature or can be pre-heated.

[0140] In order to start up the POX zone 12 in the beginning, the gas will be combusted at over-stoichiometric conditions (λ above 1) in order to heat up the reactor to the target operation temperature. Optionally, the heat-up could also be achieved by a separate start-up burner or via electrical heating means. As soon as the target temperature is achieved, the operation mode is switched to POX operation, hence to a steady operation of the reactor. The temperatures and the ratios (and other values) herein are referring to the reactor operation in its continuous mode (i.e. steady state) and thus not to the start-up of the reactor.

[0141] The result of the above described method and the corresponding gas production device 100 is a low-tar- and low-dust product gas, which contains less tar and less dust as compared to conventional methods and devices/reactors.

Modification

[0142] Fig. 3 shows a sectional view of a modification of the embodiment of the invention where the gas treatment reactor is located laterally to an updraft gasification reactor. The same reference numerals refer to the same or analogous features. Thus, reference is made to the above described embodiment and only the difference of the modification to the embodiment is described below.

[0143] The POX zone 12 of this modification has a different orientation of its length-direction as compared to the embodiment of Fig. 1. Consequently, the flow of the product gas and the injection of the oxidising agent can be performed in different directions. As an example, Fig. 3 shows an injection of the oxidising agent into the POX zone 12 via the nozzles 22 (c.f. arrow "IVb") and via at least one further nozzle at the start of the POX Zone (c.f. arrow "IVa").

[0144] This construction allows for a more compact setup of the gas production device 100.

Further Modification

[0145] A modification of the exemplary embodiment is shown in Fig. 4. Hereby, an updraft pyrolysis reactor can be combined with a gas treatment reactor.

[0146] The disclosed exemplary embodiments, as discussed in more detail afterwards, are suitable for slow pyrolysis systems that include an updraft fixed or moving-bed slow pyrolysis reactor for producing biochar and combustible gases with low particulate matter and high tar contents and a close-coupled gas treatment reactor (POX reactor) for partially oxidising the combustible gases to produce a product gas with a low tar content.

[0147] In detail, Fig. 4 shows a sectional view of an exemplary embodiment of the invention where the gas treatment reactor 2 is located vertically above the pyrolysis reactor 1b. The gas treatment reactor 2 is placed on top of the pyrolysis reactor 1b.

[0148] The fuel (as indicated by the Arrow "I") is fed into the upper region of the fuel bed 3 of the pyrolysis reactor, which is preferably a cylindrical or rectangular reactor, and forms a packed-bed on the grate 4.

[0149] The height of the pyrolysis reactor needs to be high enough to provide sufficient residence time for a complete charring process/method. The height of the fuel bed 3 inside the pyrolysis reactor can preferably be held almost constant by means of a mechanical level control or sensors based on radar or ultrasonic sound 8.

[0150] The fuel bed is heated up to at least 450°C at the bottom of the reactor in order to run the pyrolysis reactions in the absence of any oxidising agent. Heating can be realised by indirect heating via a heat exchanger, e.g. surrounding the fuel bed at the outer reactor walls (14), which for instance is supplied with energy by flue gases (as indicated by the Arrow "II") from the combustion of a share of the pyrolysis gases produced with a temperature of about 600°C or higher.

[0151] Heating could also (alternatively or in addition) be realised by electric heating elements or by injection of a pre-heated inert gas below the grate at the bottom of the reactor. The excess product gas which is not needed for reactor heating (the main share of the gas) can be used for other purposes such as e.g. application in gas engines, fuel cells or gas turbines for combined heat and power production.

[0152] As the fuel bed is heated up, pyrolysis reactions lead to the release of product gases which pass through the fuel bed and leave it at its top. The freshly supplied fuel (as indicated by the arrow "I"), which moves downwards, is at first dried by the hot product gas in a drying zone 5 before it gets pyrolysed in a pyrolysis zone 6. At the bottom of the pyrolysis reactor, the remaining charcoal drops down the grate 4 (as indicated by the arrow "III") and is discharged by means of an air tight charcoal removal system 9, e.g. by means of sealed conveying screws or a wet charcoal removal via a water bath.

[0153] The walls of the pyrolysis reactor 1b can preferably be well insulated by an appropriate outer insulation. The gas treatment reactor 2 can preferably be located vertically above the pyrolysis reactor or laterally or angular to the pyrolysis reactor. The gas treatment reactor is preferably well insulated in order to prevent tar condensation and heat losses.

[0154] In a heating section of the gas treatment reactor 2 the product gas is heated by direct or indirect energy input or from both. The product gas gets heated by radiation, conduction and convection induced by the above partial oxidation step and it can additionally be heated in a heat exchanger section (e.g. hot flue gas circulating around or in the inner walls heating means 14 of the gas production device 100, where heat is transferred to the product gas from e.g. hot flue gas). In Fig. 4, as an example, the latter option is shown and is additionally combined with a pyrolysis reactor heating. The heating of the product gas already induces a gas reforming process/method. It is to be noted that also no external heating or only a heating as shown in Fig. 1 is also possible.

[0155] The pre-heated product gas is then introduced into the partial oxidation zone / POX zone 12 of the gas treatment reactor 2 and is reformed by means of partial oxidation in the presence of an oxidizing agent, which is supplied as indicated by the arrows "IV" via nozzles 22, into the POX zone 12 in order to form a final product gas (as indicated by the arrow "V") containing significantly reduced tar levels (5 wt % or less of the tar content of the product gas at fuel bed exit). The temperature in the POX zone 12 is preferably above 800°C, more preferably above 1000°C (or even more preferably above 1,100°C) in order to achieve a highly efficient tar reduction. This temperature can be measured by a temperature sensor located in the upper part of the POX zone 12 (where rather uniform temperature conditions prevail). The measured temperature can serve as an input for a temperature controlling means (e.g. a microcomputer or a controller), which uses e.g. a PID-controlling mechanism. By the temperature controlling means, the temperature in the POX zone 12 can be adjusted by the setting amount of oxidiser supplied into the POX zone 12 (e.g. via at least one valve, which is controlled by the output of the temperature controlling means). The oxidiser may be air or oxygen or an air/steam mixture or a mixture of these gases and it can be injected at ambient temperature or can be pre-heated.

[0156] In order to start up the pyrolysis reactor and the POX zone 12, in the beginning a separate start-up burner or an electrical heating can be preferably used. As soon as the target temperature is achieved, the operation mode is switched to POX operation.

General notes for all embodiments and aspects

[0157] It is to be noted that the drying and pyrolysis of fuel particles (and hence the zones) can overlap and thus the drying zone 5 does not necessarily have to be provided separate to the pyrolysis zone 6, since in thermally thick particles drying and pyrolysis likely overlap (the corresponding conversion processes run from the outside to the inside in the reactor). Hence, Fig. 1, 2, 3 and 4 just show separate zones 5, 6 for the sake of simplicity as a pure example.

[0158] For example, due to the (optional) fuel injection

below the bed surface, the drying and pyrolysis zones are also mixed as indicated by the combined drying and pyrolysis zone 5b in Fig. 5; above zone 5b a pure pyrolysis zone 5a can be formed due to the high irradiation from the gas treatment reactor, and below zone 5b, due to the hot rising gas, a pure pyrolysis zone 5a can be formed as well. Hence, the zones as shown in the figures are purely shown for the sake of simplicity and for an explanation of an (not limiting) example.

[0159] Furthermore, Fig. 5 is provided to show a more detailed view of a possible formation of the zones inside the updraft gasification reactor 1a. In Fig. 5, a combined drying and pyrolysis zone is formed during the reaction, wherein the zone 5a describes pure pyrolysis zones and the zone 5b describes a combined pyrolysis and drying zone. The fuel is introduced into the fuel conversion reactor (in this case the updraft gasifier 1a) at the arrow "I" below the upper surface of the fuel bed, is dried and subject to pyrolysis in the zone 5b, and then the fuel moves up- and downwards and is then further subject to pyrolysis in the zones 5a. This advantageously increases the efficiency of the reaction(s) and decreases the churning or whirling of fuel particles into the flow of the initial product gas.

[0160] It is appreciated that certain features of the invention, which are, for clarity, described in the context of separate aspects, modifications or embodiments, may also be provided in combination in a single embodiment. Conversely, various features of the invention, which are, for brevity, described in the context of a single embodiment, may also be provided separately or in any suitable sub-combination.

[0161] Although the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is intended to embrace all such alternatives, modifications and variations that fall within the spirit and broad scope of the appended claims. All publications, patents and patent applications mentioned in this specification are herein incorporated in their entirety by reference into the specification, to the same extent as if each individual publication, patent or patent application was specifically and individually indicated to be incorporated herein by reference. In addition, citation or identification of any reference in this application shall not be construed as an admission that such reference is available as prior art to the present invention.

Claims

1. Method to produce a product gas with low tar and dust contents from solid biomass, biogenic residues and/or organic waste fractions with a gas production device (100),

the gas production device (100) comprising:

a fuel conversion reactor (1a, 1b), which is an updraft gasification reactor (1a) or a pyrolysis reactor (1b); and
a gas treatment reactor (2) located downstream the fuel conversion reactor (1a, 1b);

wherein the fuel conversion reactor (1a, 1b) is close-coupled with the gas treatment reactor (2); wherein the fuel conversion reactor (1a, 1b) comprises a space to contain a fuel bed (3) above a grate (4); wherein the gas treatment reactor (2) comprises the following:

a POX zone (12), and
at least one POX nozzle (22) for supplying an oxidiser into the POX zone (12); and
a gas heating zone (10) fluidic located between the space to contain the fuel bed (3) and the POX zone (12);

wherein the method comprises the following steps:

Creating an initial product gas (VI) in the fuel conversion reactor (1a, 1b);
Heating the initial product gas, which is created in the fuel conversion reactor (1a, 1b), in the gas heating zone (10);
Combusting the heated initial product gas in the gas treatment reactor (2) partially in the POX zone (12) of the gas treatment reactor (2) by injecting or supplying an oxidiser through the POX nozzles (22) into the POX zone (12).

2. Gas production device (100) for producing a product gas with low tar and dust contents from solid biomass, biogenic residues and/or organic waste fractions, the gas production device (100) comprising:

a fuel conversion reactor (1a, 1b), which is an updraft gasification reactor (1a) or a pyrolysis reactor (1b); and
a gas treatment reactor (2) located downstream the fuel conversion reactor (1a, 1b);

wherein the fuel conversion reactor (1a, 1b) is close-coupled with the gas treatment reactor (2); wherein the fuel conversion reactor (1a, 1b) comprises a space to contain a fuel bed (3) above a grate (4); wherein the gas treatment reactor (2) comprises the following:

a POX zone (12), and
at least one POX nozzle (22) for supplying an oxidiser into the POX zone (12); and

a gas heating zone (10) fluidic located between the space to contain the fuel bed (3) and the POX zone (12);

wherein the gas production device (100) is configured such that:

an initial product gas (VI) is created in the fuel conversion reactor (1a, 1b); and
the initial product gas, which is created in the fuel conversion reactor (1a, 1b), is heated in the gas heating zone (10); and
the heated initial product gas in the gas treatment reactor (2) is combusted partially in the POX zone (12) of the gas treatment reactor (2) by injecting or supplying an oxidiser through at least one POX nozzle (22) into the POX zone (12).

3. Method according to claim 1 or device according to claim 2, wherein

the chemical/physical processes in the gas production device (100) are configured such that the tar content of a final product gas (V) downstream the gas treatment reactor (2) and after the POX zone (12) is below 5 wt% of the tar content of the initial product gas upstream the gas treatment reactor (2).

4. Method according to claim 1 or 3 or device according to claim 2 or 3, wherein

at least one POX nozzle (22) is positioned at a distance to the grate (4) or an upper fuel bed surface such that the flow of gases, which is induced by the oxidiser, does not disturb the fuel bed; and/or that the surface temperature of the fuel bed (3) is kept below 450°C.

5. Method according to claim 1 or 3 or 4 or device according to anyone of claims 2 to 4, wherein

the residence time of the product gas in the gas treatment reactor (2) is above 0.2 seconds, and preferably below 1 minute, even more preferably below 10 seconds, and/or
a stoichiometric air ratio of the gas treatment reactor (2) is between 0.25 and 0.6, and preferably between 0.35 and 0.5.

6. Method according to anyone of claims 1 or 3 to 5 or device according to anyone of claims 2 to 5, wherein the gas treatment reactor (2) is located above the fuel conversion reactor (1a, 1b) in a height direction; and/or wherein the gas treatment reactor (2) is arranged laterally or angular to the fuel conversion reactor (1a, 1b).

7. Method according to anyone of claims 1 or 3 to 6 or device according to anyone of claims 2 to 6, wherein

a tar and soot reforming catalyst is provided before or after the POX zone (12) to further improve tar and soot reforming.

8. Method according to anyone of claims 1 or 3 to 7 or device according to anyone of claims 2 to 7, wherein the zones of the updraft gasification reactor (1a) comprise:

a drying and pyrolysis zone (5) in the upper part of the fuel bed, in which the solid fuel is dried and pyrolysed without the addition of oxygen;
a gasification zone (6) located below the drying and pyrolysis zone (5); and
an oxidation zone (7) located at the bottom of the fuel bed, in which the solid charcoal is converted to ashes and gases;
wherein the drying and pyrolysis, the gasification and the oxidation zones are formed over the height of the gasification reactor (1a).

9. Method according to anyone of claims 1 or 3 to 8 or device according to anyone of claims 2 to 8, wherein

the pyrolysis reactor (1b) comprises a drying zone (5) and a subsequent pyrolysis zone (6) in the fuel bed (3);
wherein the fuel and the product gas move in a counter-current direction to each other; and/or
wherein the pyrolysis reactor (1b) is externally heated or heated by a hot inert gas passing through the pyrolysis reactor (1b).

10. Method according to anyone of claims 1 or 3 to 9 or device according to anyone of claims 2 to 9, wherein the oxidiser injected into the gas treatment reactor (2) is air or oxygen or an air/steam mixture or a mixture of these gases.

11. Method according to anyone of claims 1 or 3 to 10 or device according to anyone of claims 2 to 10, wherein the method additionally comprises the step of preheating the oxidiser or the device is additionally configured to preheat the oxidiser by preheating means.

12. Method according to anyone of claims 1 or 3 to 11 or device according to anyone of claims 2 to 11, wherein the oxidiser injected into the gas treatment reactor (2) is pre-heated by the reactions in the POX zone (12).

13. Method according to anyone of claims 1 or 3 to 12 or device according to anyone of claims 2 to 12, wherein the gas treatment reactor (2) is, preferably fully, insulated in order to minimise heat losses.

14. Method according to anyone of claims 1 or 3 to 13

or device according to anyone of claims 2 to 13,
wherein a temperature in the oxidation zone (7) of a
gasification reactor (1a) is controlled by the addition
of steam or flue gas or a mixture of these gases such
that the temperature is between 800°C and 1100°C, 5
preferably between 800°C and 999°C.

15. Method according to anyone of claims 1 or 3 to 14
or device according to anyone of claims 2 to 14,
wherein at least a part of the fuel bed (3) close to the 10
bottom of the pyrolysis reactor (1b) is above 450°C
by controlling a temperature of a gas used to heat
the pyrolysis reactor externally.

16. Method according to anyone of claims 1 or 3 to 15 15
or device according to anyone of claims 2 to 15,
wherein
the POX zone (12) of the gas treatment reactor (2)
has or reaches a temperature of more than 800°C,
preferably more than 1000°C, even more preferably 20
a temperature between 1000°C and 1100°C, if cou-
pled with an updraft gasification reactor, or even
more preferably between 1,000 and 1,400°C, if cou-
pled with an updraft pyrolysis reactor.

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Fig. 1

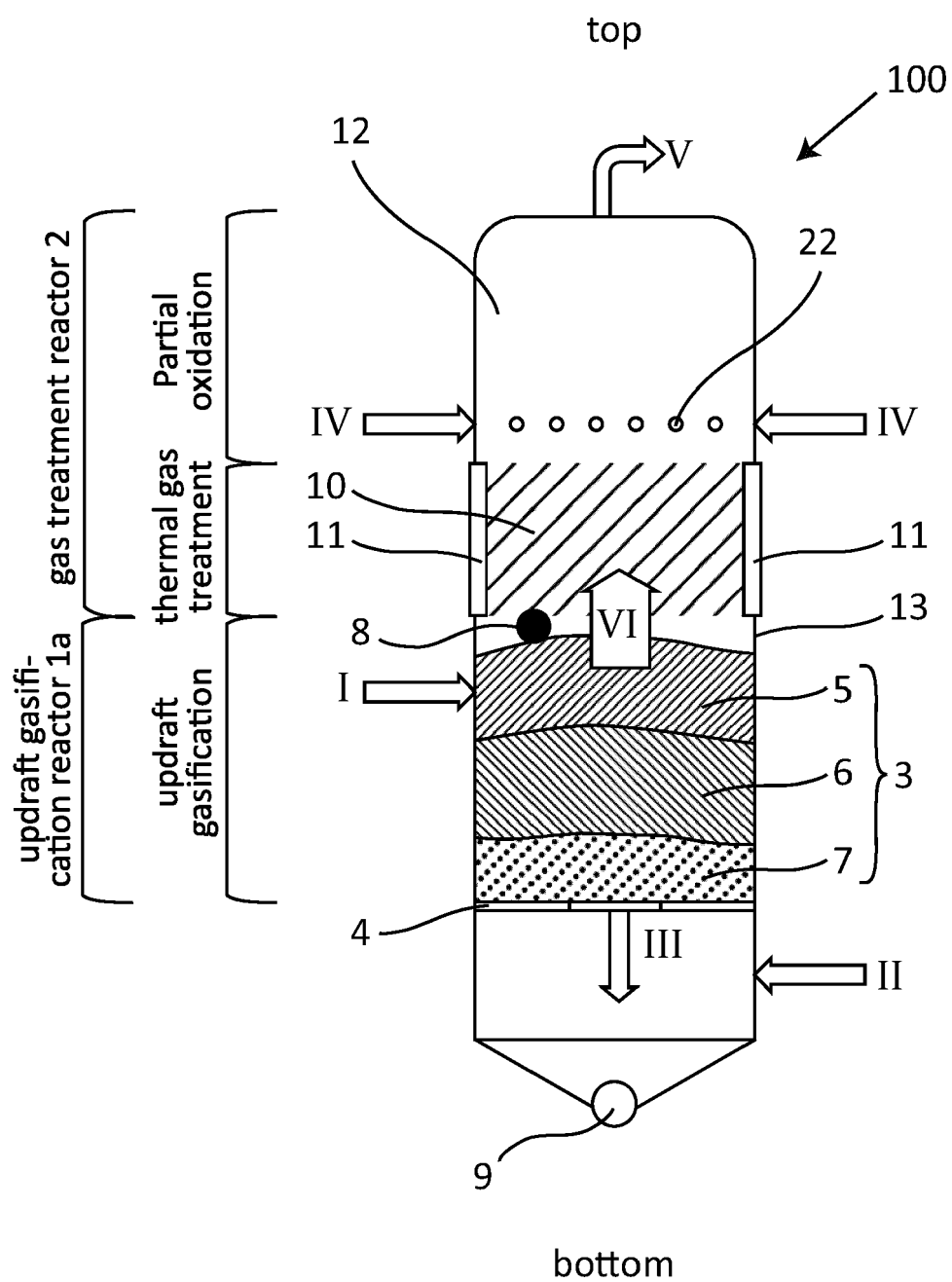


Fig. 2

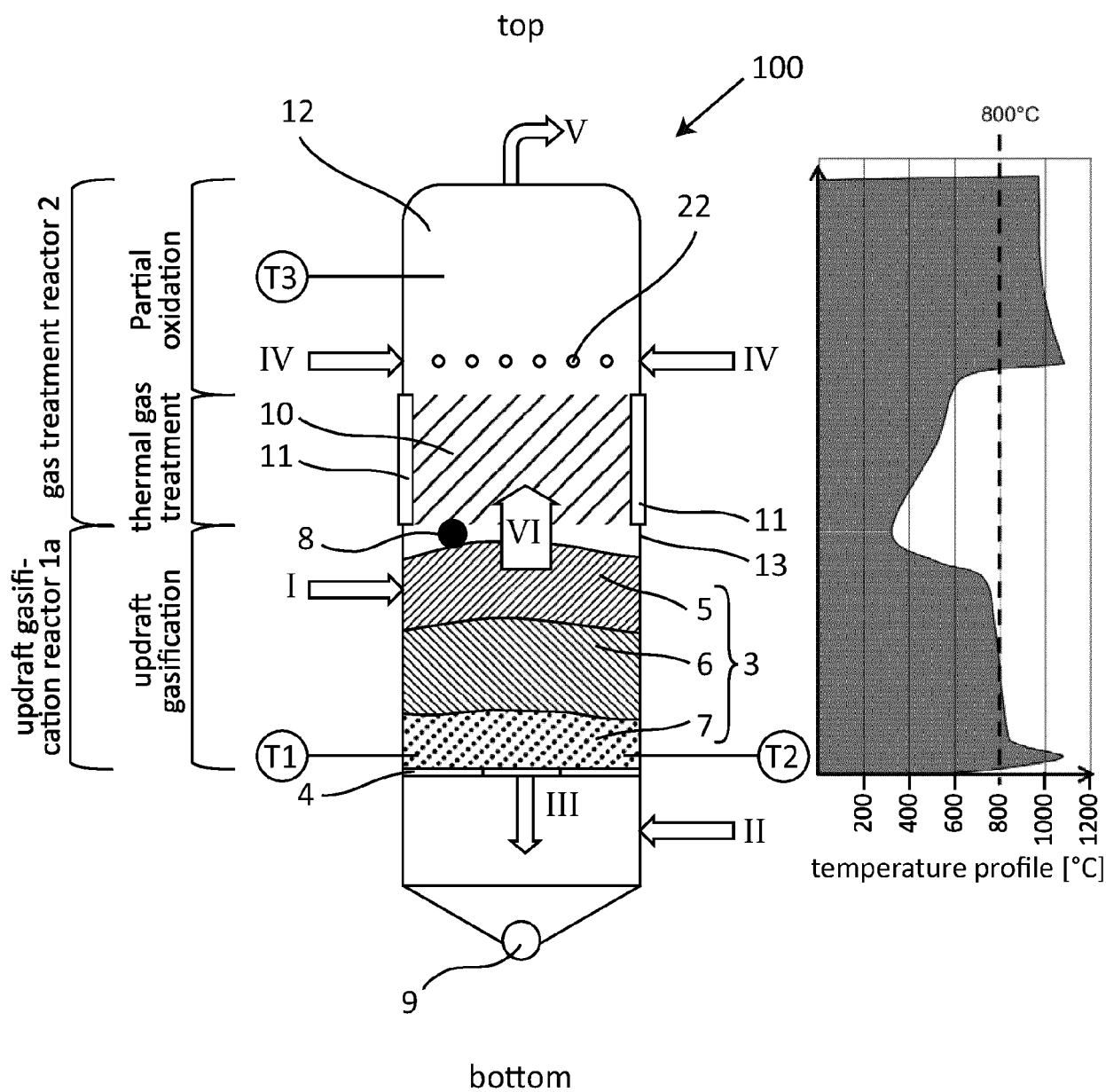


Fig. 3

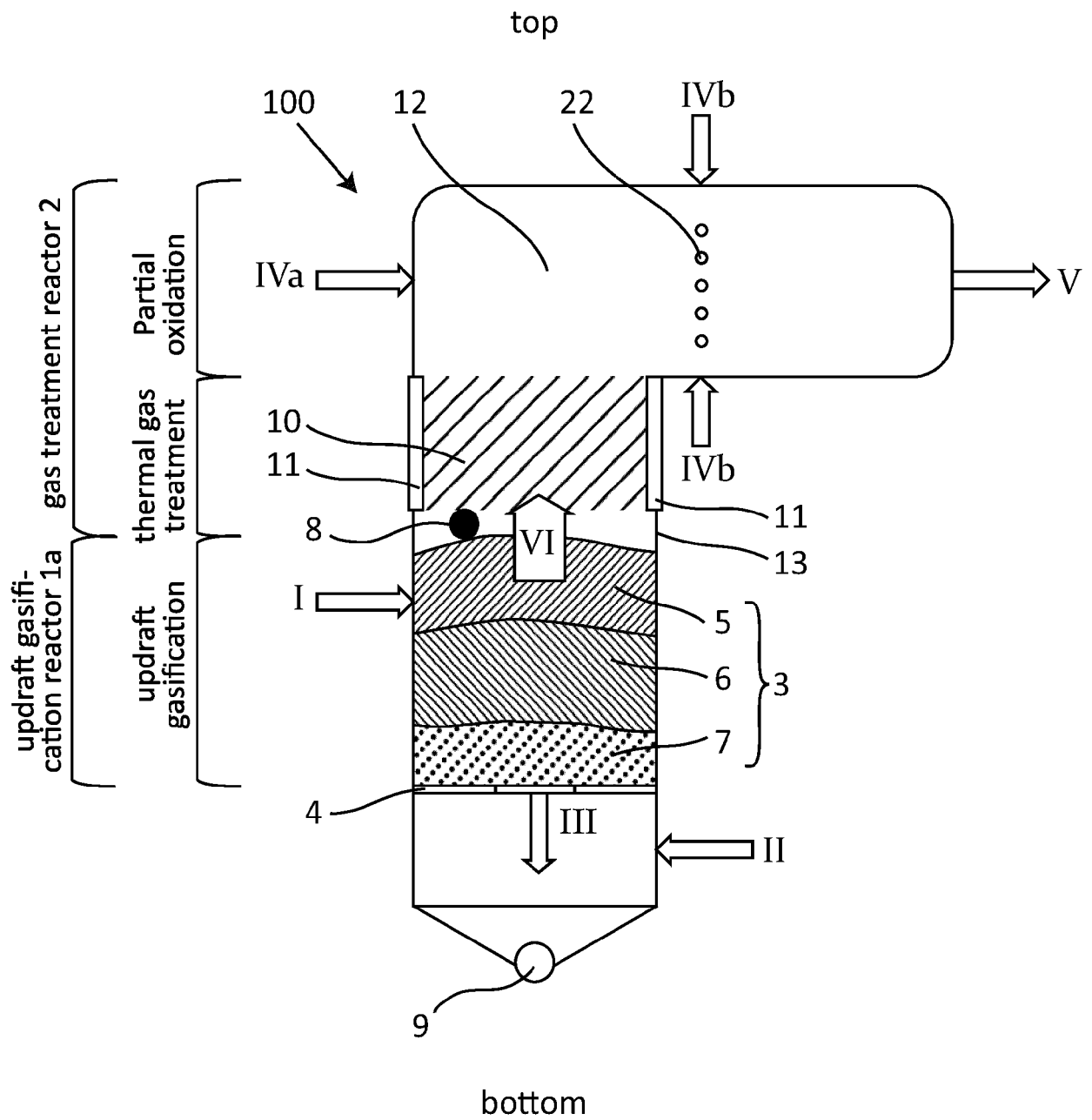


Fig. 4

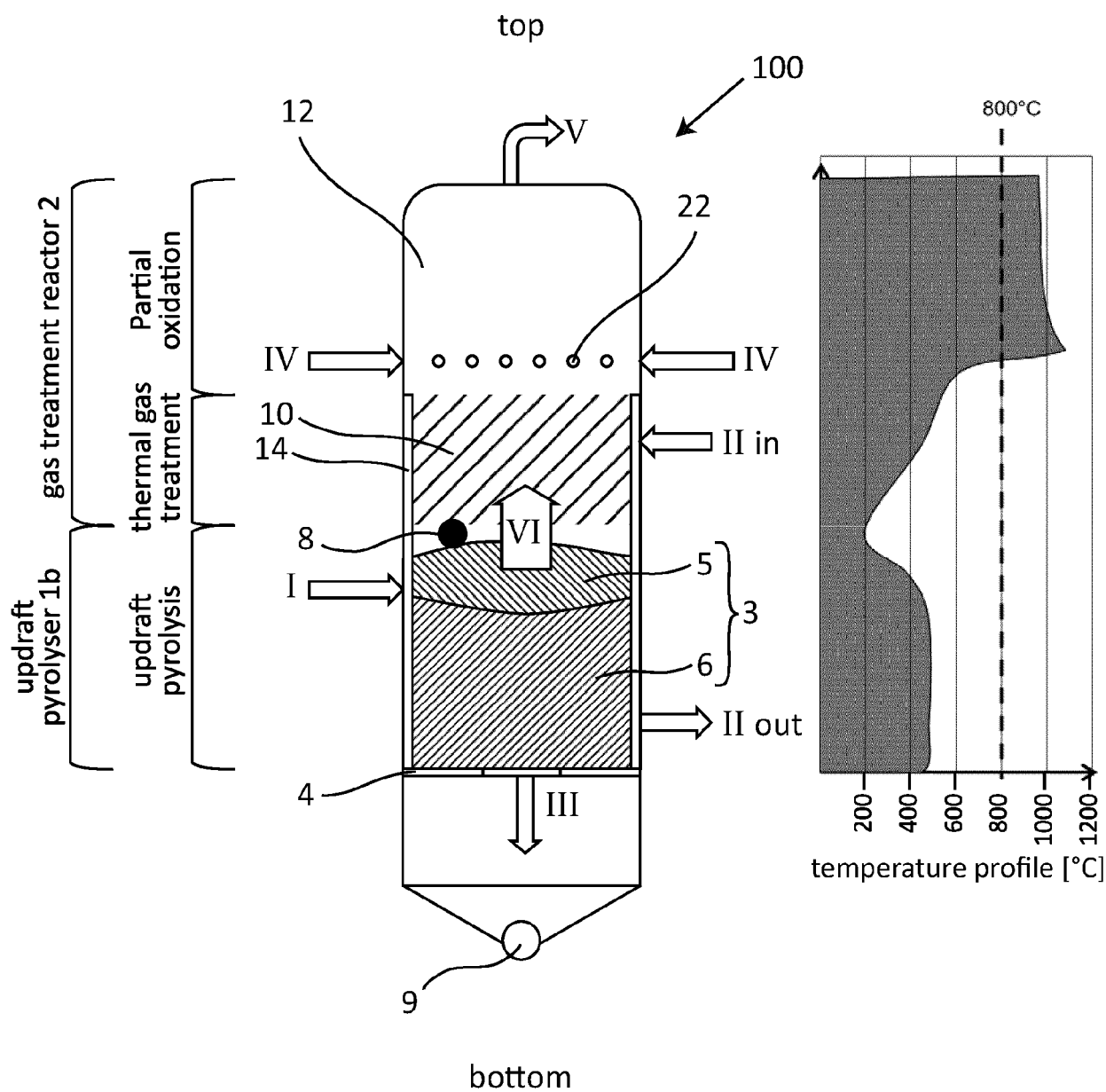
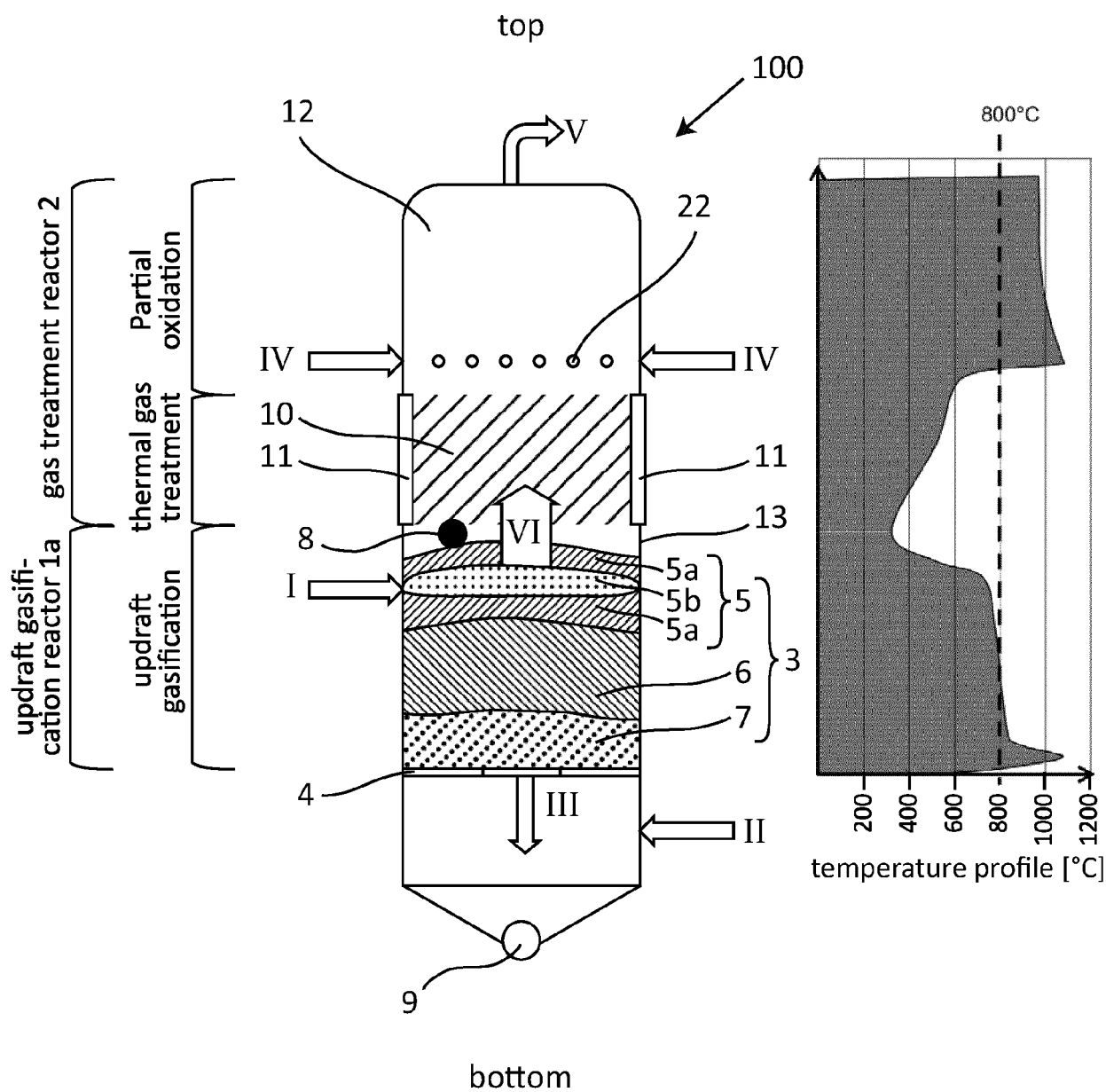


Fig. 5





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Application Number

EP 21 19 6854

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Place of search The Hague		Date of completion of the search 1 March 2022	Examiner Lachmann, Richard
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