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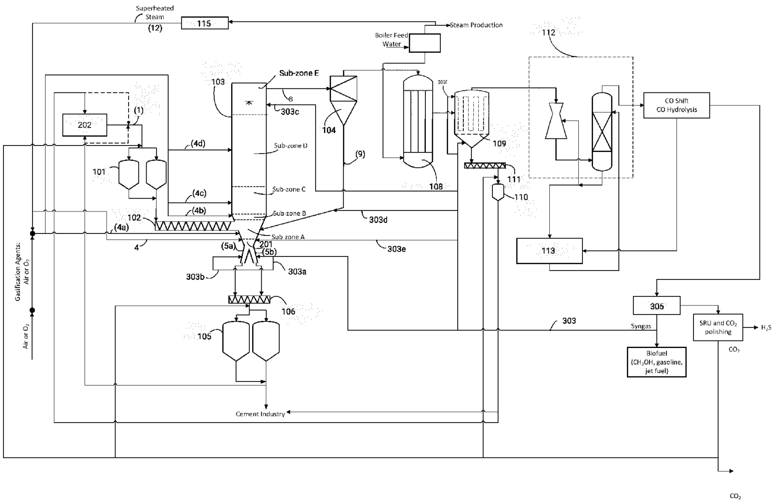
(54) PROCESS AND PROCESS PLANT FOR CONVERTING FEEDSTOCK COMPRISING A CARBON-CONTAINING SOLID FUEL

(57) The present invention provides process for converting feedstock comprising a carbon-containing solid fuel, such as biomass and/or carbon-containing solid waste material, to synthesis gas and downstream processing of the synthesis gas, the process comprising the following steps:
(a) converting the feedstock in a gasifier, the gasifier comprising a fluidized bed zone and a post-gasification zone to produce synthesis gas;
(b) obtaining the synthesis gas produced in step (a) downstream of the gasifier;
(c) recycling a portion of the synthesis gas of step (b) into at least one upstream process unit, such as the gasifier, being arranged upstream of a position in the process from which said portion is recycled.



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Description

Field of the Invention

[0001] The present invention relates to processes and process plants for the conversion of feedstock comprising a carbon-containing solid fuel such as biomass and/or carbon-containing solid waste material.

Background

[0002] Waste materials such as municipal solid waste (MSW), agricultural and industrial waste etc. are mainly landfilled and/or incinerated. Currently, waste recycling is gaining more and more attention, since it allows reuse of a large portion of the already used materials, such as paper, some plastics, glass, metals etc. However, other non-recyclable materials are still either dumped into landfills or incinerated in order to recover some of the chemical energy stored in these materials by converting it into electricity and heat. This energy, however, cannot be stored.

[0003] There is therefore a need for methods and process plants, which are able to better process these other non-recyclable materials.

[0004] Gasification of biomass and non-recyclable carbon-containing solid waste materials converts waste materials into synthesis gas thus providing the possibility to convert waste into more valuable products, such as chemicals or synthetic fuels. In other words, gasification of waste helps to recycle the waste materials differently to conventional recycling methods by converting the carbon in the waste materials into more useful molecules (i.e., synthesis gas) which can then be synthesised into valuable final products. Overall, gasifying biomass and waste materials can bring the following advantages to communities: (1) the utilization of carbon containing solid waste materials in an environmentally-friendly process, without emissions of toxic substances into the atmosphere (2) providing the most efficient way for converting the chemical energy stored in municipal solid waste (MSW) into electricity and (3) providing the most efficient way for converting the carbon content of MSW, resp. refuse derived fuel (RDF), into a highly valuable product, such as chemicals or synfuels.

[0005] Synthesis gas is typically a fuel gas mixture consisting primarily of hydrogen, carbon monoxide, and very often some carbon dioxide. It is commonly used as an intermediate in creating synthetic natural gas and for producing ammonia or methanol. Synthesis gas (syngas) may be produced by thermochemical conversion of carbon containing sourced materials, such as forest residues, agricultural residues, industrial and urban waste, etc. In general, the gasification of such carbon containing sourced materials provide raw synthesis gas which may include several impurities such as sulfur compounds (mainly hydrogen sulfide, H_2S and carbonyl sulfide, COS), ammonia, chlorine compounds (mainly HCl), volatile matters, lower and high molecular weight tars and fines (mainly in the form of micron and sub-micron fly-ash containing metal salts), and char particles (carbon contained particulates typically above 500 microns). It is desirable to be able to convert, in an efficient process and apparatus, biomass and other carbon-containing solid waste materials into more useful synthesis gas products which can then be used to produce high valuable materials, such as methanol, synthetic natural gas and/or Fischer-Tropsch synthesis fuels. For this reason, the gasification agent used in the process should not contain high values of nitrogen, which is an inert gas in the process and cannot be separated from the syngas. This means that air cannot be used as gasification agent, when the final purpose is to synthesise bio-fuels. By replacing air with O_2/water steam/CO_2 mixture, the cold gas efficiency (CGE) of the process significantly increases and the raw syngas obtained has much higher calorific value and lower volume flow rate.

[0006] The use of O_2/steam/CO_2, however, requires additional investments in production of these agents. Usually an air separation unit and steam boiler are used for industrial scale production of O_2 and steam, respectively. The CO_2 can be supplied in two ways: (i) by importing it from external supplier, means from an external combustion unit, or (ii) by separating it from the syngas in the downstream units and further recycle back to the gasification process.

[0007] Various approaches have been devised for producing, purifying, and modifying raw synthesis gas from carbon-containing solid fuel materials. These existing approaches are briefly discussed below.

[0008] US Patent No. 6063355 discloses a method for treating waste through two successive fluidized bed and combustion reactors. The solidified and/or slurry waste is introduced to the fluidized bed with revolving flow pattern at a temperature ranging from 450 °C to 650 °C, thereby producing gaseous and carbonaceous materials. These products are directly fed to a swirling flow combustion reactor, which is separate from the fluidized bed reactor, and increasing the temperature to at least 1300 °C to produce synthesis gas. The crude syngas produced in the second reactor is then quenched to separate the slag and the quenched crude syngas is passed through a cyclone and scrubber for further cleaning. This method involves the use of two successive fluidized beds which results in higher capital and operational costs.

[0009] DE 4317319 A1 discloses a gasification-based technology to produce crude synthesis gas, which is further conditioned and used as a feed for alternative end products such as methanol, cleaned synthesis gas and hydrogen. The shredded wastes are fed to two parallel-connected fixed bed gasifiers wherein the feed is reacted with oxygen, steam and raw carbon dioxide at temperatures up to 1200 °C. The produced crude synthesis gas is partly sent to an entrained-flow gasifier at a temperature of 1400 °C and pressure of 26 bar (2600 kPa) and partly to a gasification unit consisting of washing, heat recovery and cooling stages, followed by a two-stage gas scrubbing unit, COS hydrolysis and lastly used for power generation. The produced crude synthesis gas from the entrained-flow gasifier is further processed in a soot wash unit, followed by CO conversion, gas cooling and scrubbing units and finally used for producing methanol. Again, the use of two parallel fixed bed gasifiers and one entrained flow gasifier results in higher capital and operational costs.

[0010] EP 2376607 B1 discloses a method for producing and treating crude syngas from biomass through a three-step gasification and reforming process at pressure lower than 10 atm (1013 kPa). The solid biomass is fed to the bottom section, described as a gasification zone, of a fluidized bed reactor in the presence of oxygen and steam, wherein the temperature lies within the range of 500 °C to 750 °C (in the first step). The portion of said oxidized biomass produced in the first step is directly treated in a freeboard region with a residence time lower than 8s in the presence of oxygen and steam at temperatures ranging from 800 °C to 850 °C (in the second step). The portion of said oxidized biomass produced in the second step is then treated in a separate thermal reformer with oxidizing gas comprising oxygen and steam at a temperature of at least 900 °C and not exceeding a maximum of 1000 °C to produce crude syngas (in the third step). The crude syngas produced in the thermal reformer is then passed through a cyclone, followed by a heat recovery unit and finally scrubbers for further cleaning. This method has a number of disadvantages, such as:

- the third step takes place in a separated thermal reformer apparatus which means that an additional reactor is required, leading to higher capital and operational costs;
- the method is restricted to the operating pressure of the gasifier, which is below 10 atm (1013 kPa). This results in larger gasifier unit sizes being required when processing larger quantities of feedstock;
- due to shorter residence times in the post-gasification zone, heavier hydrocarbons are not completely decomposed and therefore a subsequent separate thermal reforming unit is required (as mentioned above); and
- the reliance on using external catalysts and bed material for gasification increases the operational costs of the system.

[0011] WO 2014/131700 A1 discloses a method for the recycle of by-products arising from gasification to improve the yield of the gasification plant in question which is achieved by separation of the components not reacted at temperatures of 900°C to 1200°C such as C_6H6 or $C_{10}H_8$ (by-products) and hydrogen-based products such as NH_3 which are contained in the synthesis gas and returning them to the gasification process. The return of liquid by-products into the gasifier through various embodiments covered in the patent may improve the yield of the plant but the consumption of gasification agents are still high, compared to when at least a portion of the produced synthesis gas is recycled to the gasifier.

[0012] All these processes have the disadvantage that considerable amounts of carbon dioxide are needed at various process stages, e.g. as fluidization agent or as cooling agent, therefore creating an increased carbon footprint, as the necessary CO_2 often needs to be obtained from external combustion units. In addition, due to the use of carbon dioxide, high amounts of oxygen as gasification agents are needed.

[0013] Therefore, there exists a need for processes and plants providing a reduced carbon footprint and an increased cold gas efficiency.

Summary

[0014] The problem is solved by the present invention as set forth in the independent claims.

[0015] In a first aspect, the present invention is directed to a process for converting feedstock comprising a carbon-containing solid fuel, such as biomass and/or carbon-containing solid waste material, to synthesis gas and downstream processing of the synthesis gas, the process comprising the following steps :

(a) converting the feedstock in a gasifier, the gasifier comprising a fluidized bed zone and a post-gasification zone to produce synthesis gas;

(b) obtaining the synthesis gas produced in step (a) downstream of the gasifier, in particular including refining said synthesis gas in order to produce clean synthesis gas;

(c) recycling a portion of the synthesis gas of step (b) into at least one upstream process unit, such as the gasifier, the upstream process unit being arranged upstream of a position in the process from which said portion is recycled.

[0016] In a second aspect, the present invention is directed to a process plant for converting feedstock comprising a carbon-containing solid fuel, such as biomass and/or carbon-containing solid waste material, to synthesis gas and downstream processing of the synthesis gas, the plant comprising:

a gasifier, the gasifier comprising a fluidized bed zone and a post-gasification zone and being configured to produce synthesis gas;

a downstream arrangement connected to said gasifier, the downstream arrangement being configured to obtain the synthesis gas produced in said gasifier, in particular the downstream arrangement being configured to refine the synthesis gas;

a recycling arrangement arranged downstream of the gasifier and being configured to recycle at least a portion of the synthesis gas obtained in the downstream arrangement into at least one upstream process unit, such as the gasifier, the upstream process unit being arranged upstream of a position in the process from which said portion is recycled.

[0017] The features, technical advantages, effects, and explanations with respect to the first aspect of the present application discussed herein equally apply to the second aspect of the present invention.

[0018] Due to the process and the process plant according to the first and second aspects of the present invention, in particular due step (c) of recycling of a portion of the synthesis gas to at least one upstream process unit, a significant amount of carbon dioxide which would otherwise be used in these upstream process units within a process/process plant for converting said feedstock to synthesis gas, can be substituted by synthesis gas and, therefore, the use of carbon dioxide can be significantly reduced. This leads to a reduced carbon footprint, as less carbon dioxide is needed in the process or process plant. Besides, usually the carbon dioxide used in various process units/process steps, i.e. at least one upstream process units, needs to be prepared by external combustion units. In other words, due to the present invention, synthesis gas produced in the process can be recycled, introduced, and used as a process gas in various upstream process stages/upstream process units preceding the position from which it is recycled, wherein carbon dioxide is at least partially substituted by said recycled syngas portion. For example, the recycling of a synthesis gas portion can substitute significant amounts of carbon dioxide as a fluidization agent in the gasifier and/or as a cooling agent. In addition, it has been surprisingly found that the use of the recycled syngas portion in the gasifier as fluidization agent leads to an increased carbon conversion efficiency and to a reduced need for gasification agents such as steam and/or oxygen. Furthermore, the recycled synthesis gas can substitute carbon dioxide as a dust removal agent in a filter within the process. Finally, the use of recycled synthesis gas also leads to an increased cold gas efficiency. Further technical advantages resulting from the present invention will be set forth herein below.

Brief Description of the Drawings

[0019] Certain embodiments of the present invention are shown in the accompanying drawing and hereinafter described in detail.

[0020] Figure 1 shows an example process and production plant arrangement for converting feedstock comprising a carbon-containing solid fuel, such as biomass and/or carbon-containing solid waste material to synthesis gas, according to an embodiment of the invention.

Definitions

[0021] As used herein, "upstream" is a relative term describing an earlier stage or a preceding position in the process or process plant, e.g. of a process unit, relative to the direction of the stream of the process components, i.e. feedstock and synthesis gas, through the process and plant, and, therefore, takes the usual meaning in the field. As a non-limiting example, within a classical gasification process, a gasifier is arranged upstream of a product raw gas cooler.

[0022] As used herein, "downstream" is a relative term describing a later stage or a subsequent position within the process or process plant, e.g. of a process unit, relative to the direction of the stream of the process components, i.e. feedstock and synthesis gas, through the process and plant, and, therefore, takes the usual meaning in the field. As a non-limiting example, within a classical gasification process, such as a High Temperature Winkler (HTW) process, a cyclone separator is arranged downstream of the gasifier.

[0023] As used herein, the term "recovering" is understood in a broad sense. During a step of recovering or recovery of the synthesis gas, the synthesis gas, having a corresponding composition depending on the process stage, can be treated and/or processed in accordance with any suitable treatment/processes known in the art to refine raw syngas in order to produce clean synthesis gas. These treatments typically involve removing impurities and undesired material from the synthesis gas.

[0024] As used herein, the term "average temperature" takes it usual meaning within the art and refers to the average temperature of each step and/or subzone and it will be understood that within each step and/or subzone there higher/lower temperatures than the average will likely be present. The "average temperature" can be determined in accordance with methods known to the skilled person. In particular, an average temperature can be determined by placing multiple thermocouples at different locations within a subzone in the gasifier for measuring the individual temperatures at said locations. In this measurement setup, the average temperature is the mean temperature of the individual temperatures (usually the instant gas temperatures) measured by said thermocouples (by their thermoelements) at said different locations in said subzone of the gasifier over a certain time period. In particular, if the average temperature remains constant the process conditions are considered stable.

[0025] As used herein, the term "ash softening temperature" takes its usual meaning in the art, namely the temperature at which particles of ash obtained from the feedstock will begin to deform (i.e., soften) or fuse. Ash softening temperature when referred to herein is measured experimentally using the standard method CEN/TS 15370-1.

[0026] As used herein, the term "with respect to the earth's surface" is used as a positional reference within the inventive process and process plant and the various zones in the gasifier are counted beginning from the closest distance from the earth's surface ending at the farthest distance from the earth's surface under the consideration of a set-up where the gasifier is used in an upright position with an upwards flow, i.e. away from the earth's surface, of the process components, i.e. feedstock and synthesis gas. For example, the fluidized bed zone of the gasifier is arranged at a lower position than the post-gasification zone with respect to the earth's surface. As further used herein, if a second zone is arranged "on top" of a first zone it means that the second zone directly follows the first zone, i.e. without a space in between, and the second zone being arranged at a higher position than the first zone with respect to an earth's surface.

[0027] The terms "converting a carbon-containing solid fuel to synthesis gas" and "gasification/gasifying" are used interchangeably herein.

[0028] As used herein, the term "synthesis gas" or "syngas" describes a fuel gas mixture consisting primarily of hydrogen and carbon monoxide, which can, however, depending on the process stage, include impurities, such as dust, fly ash, sulfur components and a minor amount of carbon dioxide. Therefore, in order to denote the state of the synthesis gas, i.e. to which extend it contains impurities, the process stages/process steps of gasification are additionally mentioned and/or further denotations, such as "clean" synthesis gas are additionally used. Therefore, the skilled person in the field of gasification is aware at any stage which composition the synthesis gas has.

[0029] As used herein, the term "obtaining" is to be understood broadly and mainly refers to a process step of keeping the effluent discharged from the gasifier in the process. Obtaining can also include process steps carried out downstream of the gasifier, such as recovery of synthesis gas, e.g. by separation of solids from the synthesis gas discharged from the gasifier.

[0030] As used herein, the term "pressure-loaded gasifier" means that the operating pressure within the gasifier, e.g. the fluidized bed zone and the post-gasification zone, is above atmospheric pressure. Preferably, the gasifier of the present invention, i.e. the fluidized bed and post-gasification zones are operated in a pressure-loaded mode. In other words, the gasifier of the first and second aspect of the present invention is preferably a pressure-loaded gasifier. Such pressure used to operate the pressure-loaded gasifier or a pressure-loaded gasifying process can comprise pressure ranges of between about 200 kPa and about 3000 kPa or between about 200 kPa and about 4000 kPa, more optionally between about 1000 kPa and about 3000 kPa or between about 200 kPa and about 4000 kPa.

[0031] As used herein "High Temperature Winker" gasification or abbreviated "HTW" gasification can be described as a pressure-loaded bubbling fluidized bed gasification process. The reactor for carrying out HTW gasification is called "HTW" gasifier. A HTW gasifier is the preferred gasifier for carrying out the inventive process and to be used in the inventive process plant. A HTW gasifier is a refractory-lined reactor, typically comprising a fluidized bed zone and a post-gasification zone, such as a freeboard zone, wherein the reactor is equipped with a cyclone separator and recirculation line. A HTW gasifier is typically operated under elevated pressures disclosed herein, such as about 200 kPa to about 3000 kPa or 200 kPa to about 4000 kPa, and temperatures disclosed herein with respect to the present invention. A HTW gasifier is well known in the art and for example described by S. De et al., Coal and Biomass Gasification - Recent Advances and Further Challenges, Springer Nature Singapore Pte Ltd, published 2018 which is incorporated herein in its entirety.

[0032] As used herein, the term "carbon-containing solid fuel" is any solid fuel principally which releases heat by the oxidation of carbon and which is suitable for gasification to produce synthesis gas.

[0033] As used herein, the term "recycling" is to be understood broadly and includes the process step of returning a portion of the synthesis gas obtained downstream of the reactor to at least one upstream process unit, arranged upstream from the position from where a recycling takes place, in particular for introducing said portion into the process unit and/or using the portion as a fluidization agent or a heating agent for gasification. In other words, said portion is divided from the synthesis gas product stream obtained in step (b). Said recycling can take place using conduits, valves, mass flow controllers, nozzles and/or other process equipment known to the skilled person. The recycled portion can also be used as a cooling agent. In that case, the skilled person understands that the synthesis gas obtained in step (b) from the converting step (a) is cooled to a certain extend in order to recycle a portion of it for the purpose of cooling.

[0034] The term "a portion" as used herein may refer to, unless otherwise explicitly stated, at least 1 Ma.-% (mass percent), optionally at least 5 Ma.-%, optionally at most 10 Ma.-%, optionally at most 20 Ma.-%, optionally at most 30 Ma.-%, optionally at most 40 Ma.-%, optionally at most 50 Ma.-%, optionally at most 60 Ma.-%, optionally at most 70 Ma.-%, optionally at most 80 Ma.-%, optionally at most 90 Ma.-%, optionally at most 95 Ma.-%, optionally at most 99 Ma.-%. Furthermore, a portion can comprise about 1 to about 50 Ma.-%, preferably about 2 to about 30 Ma.-% or about 5 to about 15 Ma.-%. The portion of recycled synthesis gas of step (c) according to the present invention represented in Ma.-% refers to the total mass of the synthesis gas recovered in step (b). Furthermore, as used herein, a "part" is a relative subunit of said portion which is represented in Ma.-% related to the total mass of the portion. The ranges defined above for the "portion" equally apply to the "part".

[0035] As used herein, the term "carbon conversion efficiency (CCE) represents the percentage of total carbon in the gasifier feedstock which is successfully converted to product gases, which contain carbon (such as CO, CO_2, CH_4, C2H2, C_2H_4,C_2H_6, C6H6 and $C_{10}H_8$).

[0036] As used herein, the term "about" referring to numerical values can cover the respective value in a range of ±10 %; ±5 %, ±2 %; or ±1%.

[0037] As used herein, the term "Cold Gas Efficiency (CGE)" represents the ratio of chemical energy stored in the raw syngas over the chemical energy stored in the solid feedstock.

Detailed Description

[0038] Processes and process plants for the conversion of feedstock comprising carbon-containing solid fuel, such as biomass and/or carbon-containing solid waste material, to synthesis gas are provided herein and in accordance with the present claimed invention to resolve the foregoing problems in prior art processes and process plants.

The Process

[0039] In a first aspect, the present invention is directed to a process for converting feedstock comprising a carbon-containing solid fuel, such as biomass and/or carbon-containing solid waste material, to synthesis gas and downstream processing of the synthesis gas, the process comprising the following steps :

(a) converting the feedstock in a gasifier, the gasifier comprising a fluidized bed zone and a post-gasification zone to produce synthesis gas;

(b) obtaining the synthesis gas produced in step (a) downstream of the gasifier;

(c) recycling a portion of the synthesis gas of step (b) into at least one upstream process unit, such as the gasifier, the at least one upstream process unit being arranged upstream of a position in the process from which said portion is recycled.

[0040] The position in the process from which said portion is recycled is typically a branching unit. Said branching unit is configured to branch off a portion of the synthesis gas product stream and lead said portion into a conduit for recycling into at least one upstream process unit. Devices for realizing such branching unit are well known to the skilled person.

[0041] The at least one upstream process is not limited by number. Thus, there can be more than one upstream process units, such as at least two, at least three, at least four, at least five, at least six or at least ten e.g. 1 to 4 upstream units, into which the portion of the synthesis gas is recycled. Optionally, "at least one upstream unit" can comprise one, two, three, four, five, six, seven, eight, or ten upstream units. It is well understood that the portion is further divided into parts, if more than one upstream process units are used. The number of the parts corresponds to the number of process units to which the synthesis gas is recycled. For example, if two upstream process units are used, there are two parts of the portion. The percentage of each part is not limited, but usually, the portion is divided into equal parts (i.e. 50:50 in case of two process units) in case more than one upstream process unit is used. In a particular embodiment, only one upstream process unit, for example the reactor, is used.

[0042] In certain embodiments, combinable with each other embodiment disclosed herein, the at least one upstream process unit comprises the gasifier. Further features of the gasifier are described below in the section "The Gasifier". At least a part of the portion of the synthesis gas of step (c), such as at least 25 Ma.-%, at least 50 Ma.-% or at least 75 Ma.-%, or 100 Ma.-% of the portion, can be recycled into the gasifier. Said recycling synthesis gas portion of step (c) is introduced into an inner volume of the gasifier where the conversion according to step (a) takes place. The recycled portion in step (c) can be ranging from about 2 to about 30 Ma.-%, preferably from about 5 to about 15 Ma.-% with respect to the produced synthesis gas. Said introducing can for example be carried out by a nozzle or other means known to the skilled person. Preferably step (c) comprises at least one of the sub-steps:

(c1) recycling the portion of the synthesis gas of step (b) into the fluidized bed zone; and/or

(c2) recycling the portion of the synthesis gas of step (b) into the post-gasification zone.

[0043] In step (c1) the recycled synthesis portion can be directly introduced into the fluidized bed zone over an inlet, such as a nozzle, in the gasifier wall encasing the fluidized bed zone and/or by introducing the portion over a zone below (with respect to the earth's surface) the fluidized bed zone and/or by introducing the portion over a recycle line, which is explained in more detail below. The recycled portion in step (c1) can be ranging from about 2 to about 30 Ma.-%, preferably from about 5 to about 15 Ma.-%, e.g. about 10 Ma.-%, with respect to the produced synthesis gas. Said step (c1) automatically includes fluidizing the fluidized bed by the recycling portion of the synthesis gas. The fluidization velocity provided by the contribution of the recycling according to step (c1) can range from about 0.5 to about 1.6 m/s being the typical fluidization velocity for a fluidized bed. Due to recycling in step (c1) a significant portion of carbon dioxide, which is usually employed as a fluidization agent, can be substituted by the recycled synthesis gas portion, therefore, significantly reducing the carbon footprint of the process, even independently of the composition of the feedstock. In other words, the carbon dioxide consumption for fluidization can be significantly reduced.

[0044] Surprisingly it was found that the recycling according to step (c1) has further unexpected technical advantages. It was surprisingly found that the recycling of a portion of synthesis gas considerably decreases the demand of gasification agent, in particular oxygen and steam, and at the same time increases the conversion efficiency of the feedstock. Such reduction of oxygen demand is in particular very advantageous in terms of process costs, as the production of oxygen is very expensive. As a non-limiting example, a recycling portion of about 10 Ma.-% of the synthesis gas obtained in step (b) can reduce about 2 Ma.-% or more of overall oxygen consumption, depending on the feedstock composition, for gasification compared to conventional processes operating without recycling of synthesis gas. Such reduction of oxygen consumption can lead to considerable cost savings in a process or process plant, as oxygen is expensive to produce.

[0045] Without wishing to be bound by a particular theory, it is partly assumed that the surprising and additional effects lie in the particular nature of synthesis gas. In terms of the reduced consumption of oxygen and steam, synthesis gas has a lower molar heat capacity compared to carbon dioxide. Because of the difference in molar heat capacity, it is assumed that carbon dioxide acts as an energy sink within the gasification zones compared to synthesis gas and, therefore, the use of carbon dioxide requires a higher amount of oxygen in order to compensate for temperature drop. In terms of the increased cold gas efficiency (CGE) and also in terms of the reduced need of gasification agents, it is further assumed that, due to the increased higher heating value of synthesis gas compared to that of the feedstock, the recycled synthesis gas portion acts as an additional energy source and, therefore, favourable influences thermodynamics, in particular the thermochemistry, in the fluidized bed zone. In particular, the effect of the higher heating value of the recycled synthesis gas allows for the carbon content in the feedstock to react exothermically resulting in the formation of CO, thereby enhancing the carbon gasification efficiency of the process.

[0046] In step (c2) a recycling of the portion can take place into the post-gasification zone, for example as a cooling agent, as described further below. In this case, the portion obtained in step (b) has been at least subjected to a cooling according to step (b2).

[0047] In certain embodiments, being combinable with any other embodiment disclosed herein, step (b) comprises the sub-steps of:

(b1) cooling the synthesis gas produced in step (a) by a raw gas cooler downstream of the gasifier to obtain a cooled synthesis gas;

(b2) filtering the cooled synthesis gas obtained in step (b1) by a filter unit, such as a fly-char (dry basis) removal unit, to obtain a filtered synthesis gas;

(b3) cleaning the filtered synthesis gas obtained in step (b2) by a washing unit, such as a quench and scrubbing unit, to obtain a purified synthesis gas;

(b4) removing carbon dioxide from purified synthesis gas obtained in step (b3) using a CO shift and CO hydrolysis unit to obtain clean synthesis gas; and optionally

(b5) removing further carbon dioxide and H_2S in an acid gas removing unit to produce clean synthesis gas for further processing.

[0048] Preferably, the synthesis gas of which a portion is recycled in step (c) is selected from the any of the synthesis gases obtained in any of steps (b1) to (b5) or a combination thereof.

[0049] In other words, the composition of the synthesis gas of which a portion is recycled to the gasifier is not critical.

[0050] Nevertheless, it is preferred that the portion of the synthesis gas of step (c) is recycled is the clean synthesis gas from step (b5). The units in which steps (b1) to (b5) are carried out are well known to the skilled person.

[0051] After recovering the clean synthesis gas from step (b5), the portion which is not recycled to an upstream process unit of the synthesis gas can be further processed into an appropriate feedstock for production of various useful products such as advanced/bio-fuels, by processes known to those skilled in the art. Such processes can offer tar-free syngas as an appropriate feedstock to produce high valuable materials, such as methanol, synthetic natural gas and/or Fischer-Tropsch synthesis fuels.

[0052] In certain embodiments, being combinable with each other embodiment disclosed herein, the synthesis gas portion in step (c) is ranging from about 1 Ma.-% to about 70 Ma.-%, preferably about 2 Ma.-% to about 30 Ma.-% or to about 40 Ma.-%, more preferably about 5 Ma.-% to about 15 Ma.-%, even more preferably from about 5 Ma.-% to about 10 Ma.-%, in relation to the total mass of synthesis gas obtained in step (b). Preferably, the synthesis gas obtained in step (b) is the synthesis gas obtained in step (b5).

[0053] The further components of the process according to the present invention are described in the following sections "The Gasifier", "The Feedstock" and "The Upstream Process Unit".

The Gasifier

[0054] The gasifier comprises a fluidized bed zone and a post-gasification zone i.e., both zones are present in a single reactor (i.e., gasifier). In certain embodiments, the fluidized bed zone is below the post-gasification zone with respect to the earth's surface. Preferably, the gasifier is a HTW gasifier. A fluidized bed zone takes its usual meaning in the art and in HTW gasification, namely a bed of material in which the properties during operation are such that the material therein behaves as a fluid. In certain embodiments, the bubbling fluidized bed includes internally produced solid remnants of gasified feedstock, termed here as bed material. In general, the bed materials can have a particle size ranging from about 200 to about 1600 microns.

[0055] The post-gasification zone as used herein also takes its usual meaning in the art and in HTW gasification. In preferred embodiments, the post-gasification zone is a freeboard zone.

[0056] The gasifier is preferably pressure-loaded during operation. As already defined, this means that the gasifier is preferably operated at pressures above atmospheric pressure. In particular, the gasifier, i.e. the fluidized bed zone and the post-gasification zone, is operated at a pressure of between about 200 kPa and about 3000 kPa or between about 200 kPa and about 4000 kPa, optionally about 1000 kPa to about 3000 kPa or to about 4000 kPa, optionally wherein the gasifier is a refractory lined reactor. The advantages of the elevated operating pressures have already been explained herein.

[0057] In certain embodiments, combinable with all other embodiments disclosed herein, the particulate matter has a residence time in the fluidized bed zone of at least about 8 minutes. Preferably, the residence time is about 8 minutes to about 90 minutes, preferably about 15 minutes to about 75 minutes, preferably about 25 minutes to about 60 minutes, preferably about 35 minutes to about 45 minutes. As used herein, the term "residence time of particulate matter in the fluidized bed zone" may be understood as the time period from an entry of a solid material into the fluidized bed to the time point said solid material leaves the fluidized bed from the bottom of the gasifier as a bottom product. Said residence time can be measured by methods well known to the skilled person.

[0058] In certain embodiments, combinable with all other embodiments disclosed herein, the raw synthesis gas in has a residence time in the post-gasification zone of at least about 7 or 8 seconds, preferably at least about 10 seconds, preferably at least about 12 seconds, preferably at least about 15 seconds. Preferably the residence time in the post-gasification zone is no greater than about 20 seconds, preferably no greater than about 15, preferably no greater than about 10 seconds. The higher residence times in the post-gasification zone help to improve the thermal decomposition of the heavier hydrocarbons, thus helping to reduce the amount of tar present in the syngas product. In particular, the term "residence time of raw synthesis gas in the post gasification zone" may be understood as the time period from the entry of a raw synthesis gas molecule, produced in the fluidized bed, into the post gasification zone until the exit of the raw synthesis gas molecule from the post-gasification zone. Said residence time can be determined by common methods known to the skilled person. The higher residence time of more than 8 seconds in the post gasification zone which can immensely improve the thermal decomposition of the heavier hydrocarbons

[0059] The flexibility of operating conditions in the gasifier by operating at higher pressures, up to 4000 kPa, which offers more compacted units for higher production capacity, offering appropriate flowrate, and operating conditions for the bio-fuel production processing which basically calls for higher pressure and flowrate of synthesis gas stream. Furthermore, it is advantageous that the availability of pressurized synthesis gas downstream of the process facilitates the possibility of recycling of synthesis gas without additional need for pressurization.

[0060] In certain embodiments, combinable with all other embodiments disclosed herein, the gasifier comprises a conical portion. In certain embodiments, combinable with all other embodiments disclosed herein, the fluidized bed zone is located within the conical portion and the post-gasification zone is located within the non-conical portion. In certain embodiments, the conical portion is angled between 3 and 12 degrees. Having the fluidized bed zone situated in the conical portion allows nearly constant gas velocity and uniform oxygen supply across the height of fluidized bed with the advantage of controlled process conditions leading to homogeneous bubble formation in the fluidized bed zone which enhances thereby partial oxidation and thermal decomposition of the feedstock.

[0061] In preferred embodiments, an external catalyst is not added into the system i.e., the gasifier is operated absent the addition of external (or fresh) catalyst. This means that no external catalyst is specifically added into the gasifier during operation. Instead, in the preferred embodiment, the ash material within the feedstock is essentially used as the catalyst. In this respect, the bottom product of the present process typically contains both ash and carbon and the ash contains a lot of different materials such as aluminum, iron, nickel, etc. which act as the catalyst. As is explained herein, it is particularly advantageous not to have to handle and add an external catalyst into the process.

[0062] The operating temperatures of the gasifier are dependent on the ash softening temperature of the feedstock to be gasified. Therefore, in preferred embodiments the ash softening temperature of the feedstock to be gasified is measured prior to operating the gasifier.

[0063] In certain embodiments the fluidized bed zone comprises the following subzones, starting from the lowest position of subzone A with respect to the earth's surface:

- Subzone A in which a process step (a1) of contacting the feedstock with a gasification agent comprising steam and oxygen is carried out, at an average temperature in the range of between about 350-400°C below the ash softening temperature of the feedstock, to partially oxidize the feedstock; and

- Subzone B, being arranged on top of subzone A, in which a process step (a2) of contacting the partially oxidized product produced in step (a1) with a gasification agent comprising steam and oxygen is carried out, at a higher average temperature than in step (a1) and at an average temperature in the range of between about 250-350°C below the ash softening temperature of the feedstock;

and/or wherein the post-gasification zone comprises the following subzones starting from the lowest position of subzone C with respect to the earth's surface:

- Subzone C, being arranged on top the fluidized bed zone, in which process step (a3) of contacting at least a portion of the product produced in the fluidized bed zone, in particular in process step (a2), with a gasification agent comprising steam and oxygen is carried out, at a higher average temperature than in the fluidized bed zone, in particular than in process step (a2), the average temperature being between about 200-300°C below the ash softening temperature of the feedstock; and
- Subzone D, being arranged on top of subzone C, in which process step (a4) of contacting at least a portion of the product produced in process step (a3) with a gasification agent comprising steam and oxygen is carried out at a higher average temperature than in process step (a3), the average temperature being between about 100-250°C below the ash softening temperature of the feedstock, to produce the synthesis gas.

[0064] In a preferred embodiment, at least a part of the portion of step (c) is recycled and introduced into subzone A. Furthermore or alternatively, the post-gasification zone further comprises:

- Subzone E, arranged on top of subzone D, in which process step (a5) of cooling at least a portion of the product produced in process step (a4) to an average temperature lower than in process step (a4) is carried out, the synthesis gas within this subzone E being cooled by about 50°C to about 100°C; and

- wherein at least a part of the synthesis gas portion in step (c) is recycled into subzone E for cooling.

[0065] The temperatures mentioned above for Subzones A to E are controlled by the supply of the gasification agent.

[0066] The gasification agent comprises oxygen and steam. In certain embodiments, the gasification agent further comprises any other suitable gasification agent. In certain embodiments, the gasification agent further comprises air. In certain embodiments the gasification agent further comprises CO_2. In certain embodiments, the gasification agent is oxygen and steam i.e., the gasification agent does not comprise any other substantial gas (with the exception of impurities). Preferably, the gasification agent is either oxygen and steam or oxygen, steam and air, most preferably oxygen and steam. In possible alternative embodiments, the gasification agent is air. The gasification agent is fed into the fluidized bed zone of the gasifier using any suitable feeding means.

[0067] It is preferred that the gasification agent is introduced into the gasifier via a controlled flowrate, optionally through a single or multilayered nozzle system, as is described in more detail herein.

[0068] In some embodiments, the content of the gasification agent and the amount of gasification agent introduced into the gasifier will depend on the identity quality of the feedstock and its characteristics and properties. In some embodiments, this includes properties of the feedstock such as the fixed carbon content, heating value, ash melting point, and metal content and other impurity levels. In certain embodiments, the content and amount provided should be sufficient to partially oxidize and thermochemically decompose the feedstock to high quality, tar free syngas, as will be understood in the art. Ultimately, in preferred embodiments the gasification agent is selected so as to be sufficient to convert the feedstock to raw syngas.

[0069] In certain embodiments, subject to the specific feedstock that is used in the process, the gasification agent is supplied to the gasifier so that the oxygen content in the gasifier is in the controlled range of 0.28 - 0.52 Nm^3/kg (daf) of the feedstock, of which at least about 20% and not greater than about 80% is supplied to the fluidized bed zone. In further embodiments, the gasification agent is supplied to the gasifier so that the oxygen content in the gasifier is in the controlled range of 0.35 - 0.45 Nm^3/kg (daf) of the feedstock, of which at least about 35% and not greater than about 65% is supplied to the fluidized bed zone.

[0070] daf or DAF = Dry Ash Free content, the weight percentage from the dry and ash free material, is calculated as follows:

$$\text{daf} = 100 / (100 - \text{TM} - \text{ash})$$

where, TM = total moisture content of the feedstock, ash = ash content in the feedstock. TM is calculated using ISO 18134-1 and ash content using ISO 18122 standard.

[0071] In certain embodiments, subject to the specific feedstock that is used in the process, the gasification agent is supplied to the gasifier so that the amount of steam in the gasifier is in the controlled range of 0.23 - 0.52 Nm^3/kg (daf) of the feedstock, of which at least about 40% and not greater than about 80% is supplied to the fluidized bed zone. In further embodiments, subject to the specific feedstock that is used in the process, the gasification agent is supplied to the gasifier so that the amount of steam in the gasifier is in the controlled range of 0.30 - 0.45 Nm^3/kg (daf) of the feedstock, of which at least about 50% and not greater than about 70% is supplied to the fluidized bed zone.

[0072] The gasifier comprises a fluidized bed zone and a post-gasification zone i.e., both zones are present in a single reactor (i.e., gasifier). In certain embodiments, the fluidized bed zone is below the post-gasification zone. A fluidized bed zone takes its usual meaning in the art and in HTW gasification, namely a bed of material in which the properties during operation are such that the material therein behaves as a fluid. In certain embodiments, the bubbling fluidized bed includes internally produced solid remnants of gasified feedstock, termed here as bed material. In general, the bed materials mayhave a particle size ranging from about 200 to about 1600 microns.

[0073] In certain embodiments the gasifier comprises a conical portion. In certain embodiments, the fluidized bed zone is located within the conical portion and the post-gasification zone is located within the non-conical portion. In certain embodiments, the conical portion is angled between 3 and 12 degrees. Having the fluidized bed zone situated in the conical portion allows nearly constant gas velocity and uniform oxygen supply across the height of fluidized bed with the advantage of controlled process conditions leading to homogeneous bubble formation in the fluidized bed zone which enhances thereby partial oxidation and thermal decomposition of the feedstock.

[0074] The operating temperatures of the gasifier are dependent on the ash softening temperature of the feedstock to be gasified. Therefore, in preferred embodiments the ash softening temperature of the feedstock to be gasified is measured prior to operating the gasifier.

[0075] The ash softening temperature of some example feedstocks at reducing atmosphere condition are provided below:

Feedstock type	Ash softening temperature (°C)
Mix of refuse derived fuels (RDF) and municipal solid waste (MSW)	1178
MSW	1180
RDF with plastic	1130
Untreated wood	1372
Hard wood	1456
Lignite	1150

(continued)

Feedstock type	Ash softening temperature (°C)
Bituminous coal	1270

[0076] The above values are taken from particular feedstocks which have been tested. In general, RDF will have an ash softening temperature ranging from 1130 to 1230 °C and typical untreated and hard-wood from 1150 to 1600 °C, although impurities therein can result in ash softening temperatures falling outside of these ranges. The temperature ranges are therefore merely provided as approximate ranges.

[0077] It has been identified that operating the gasifier at temperatures based on the ash softening temperature of the feedstock results in a highly efficient conversion of the feedstock to synthesis gas. Operating the process within these temperature ranges has been found to advantageously avoid melting the ash in the gasifier and the particles becoming sticky, which can lead to agglomerations that damage the fluidized bed.

[0078] The biomass and/or carbon-containing solid waste material feedstock (as discussed in detail earlier) is supplied to the gasifier (by means discussed in detail earlier), preferably in pelletized form. Preferably, the feedstock is supplied to the gasifier in the fluidized bed zone i.e., via an entry point in the fluidized bed zone. In certain embodiments the feedstock is supplied to the gasifier at up to 3 different entry points within the fluidized bed zone. In certain embodiments, there are 3 entry points, in other embodiments 2 entry points and in further embodiments only 1 entry point.

[0079] In certain embodiments, the gasification agents are supplied to the gasifier at multiple locations along the gasifier. In certain embodiments, the gasification agent is supplied to both the fluidized bed zone and the post-gasification zone of the gasifier. In certain embodiments, the gasification agent is supplied to the gasifier at approximately 2 to 15 locations along the gasifier, preferably 4 to 10 locations, preferably 5 to 8 locations along with the gasifier.

[0080] In certain embodiments, the gasification agent is supplied to the gasifier via a plurality of nozzles. In certain embodiments, each of the nozzles are multilayered. In preferred embodiments, at least one of the nozzles is arranged at an acute angle relative to a horizontal plane of the gasifier. In certain embodiments, the nozzles are tuyeres.

[0081] In certain embodiments, being combinable with all other embodiments disclosed herein, the gasifier further comprising a sedimentation subzone with at least one discharge leg, the sedimentation zone being arranged below the fluidized bed zone with respect to the earth's surface, wherein

- heavy solid residues migrating in a downwards direction within the gasifier and being obtained in the fluidized bed zone are discharged from the at least discharge leg of the sedimentation zone; and

- at least a part of the synthesis gas portion of step (c) is recycled to the sedimentation zone, in particular into the at least one discharge leg. In other words, step (c1) further comprises introducing the recycled synthesis gas portion as a fluidization agent in over the at least one discharge leg of the gasifier. In this case, the technical advantages as discussed above are even more pronounced, as the recycled portion, e.g. of step (c1), enters the fluidized bed from below and comes into contact with the entire fluidized bed. In particular, the sedimentation zone has two discharge legs at the lowest position, with respect to the earth's surface, of the reactor. The average temperature the sedimentation zone is lower than the average temperature in subzone B and is between 400-500 °C below the ash softening temperature of the feedstock. In the sedimentation subzone the bottom product, i.e. heavy solid residues, is treated with a gasification agent comprising steam (and CO_2).

[0082] In certain embodiments, a cyclone separator, in which entrained dust particles are separated from the synthesis gas, is arranged downstream of the gasifier. In certain embodiments, the cyclone removes a majority (greater than 50 Ma.-%) of entrained dust. In certain embodiments, the cyclone removes a majority (greater than 50 Ma-%) of pyrolytic fly-ash/char with a particle size greater than 10 microns. Any suitable cyclone apparatus may be used that is suitable for use in a gasification process. In certain embodiments, the cyclone comprises a return line to return/recycle the separated material (i.e., dust) directly back to the gasifier, optionally the fluidized bed zone of the gasifier. This helps to improve the carbon conversion efficiency of the system and process. In certain embodiments, the return line is positioned at the bottom of the cyclone. In certain embodiments, the synthesis gas product is treated in the cyclone directly after leaving the gasifier i.e., the cyclone is the first post-treatment step, situated directly downstream of the gasifier.

[0083] Preferably, the solids are recycled into the gasifier by a return line which connects said cyclone separator and the gasifier; and wherein the at least one upstream unit comprises the return line at least a part of the synthesis gas portion of step (c) is recycled and introduced into the return line. This helps the introduction of the portion of step (c) as a fluidization agent for the fluidized bed and is connected to the technical advantages described above.

[0084] Furthermore or alternatively, an intermediate cooling unit is arranged downstream and outside of the gasifier and upstream of the cyclone separator, wherein the at least one upstream unit comprises the intermediate cooling unit and at least another part of the synthesis gas portion of step (c) is recycled and introduced into the intermediate cooling unit; and wherein the cyclone separator is a cyclone candle filter unit. A cyclone candle filter unit is a cyclone separators as commonly used in the field HTW gasification but also including a candle filter, as also known to the skilled person, at the synthesis gas effluent in order to filter fine particles, i.e. particles having sizes below 5 μm, out of the synthesis gas stream. Compared to conventional cyclone separator, having a separation efficiency for such fine particles of at most 95%, a cyclone candle filter unit has a separation efficiency of 99.99%. Such cyclone candle filter unit is for example known from CN 201684496 U, which is incorporated by reference herein in its entirety. However, if the temperature of the gas is too high, the dust particles irreversibly clog the filter. Therefore an intermediate cooling unit is needed. The recycled portion of step (c) can also be used as a coolant in the intermediate cooling unit. However, in this particular embodiment, the recycled synthesis gas is primarily used to clean the filter. The dust adsorbed on the candle filter surface is usually removed by carbon dioxide as a cleaning gas, e.g. by applying pulses. Recycling a portion of synthesis gas to the candle filter unit to replace carbon dioxide as the cleaning gas can lead to considerable reduction in carbon dioxide consumption of the process. In other words, the recycled synthesis gas is using as pulsing gas in order to remove dust adsorbed on the candle filter surface. In certain embodiments, being combinable with each of the embodiments disclosed herein, an intermediate cooling unit is the intermedia cooling unit disclosed in WO 2018/228946 A1, which is incorporated by reference herein in its entirety.

[0085] In certain embodiments, the process further comprises the step of densifying, in particular pelletising, the feedstock prior to an introduction into the gasifier. Using carbon-containing solid fuel feedstocks in the form of pellets which is favourable for feedstock to be used at elevated pressure conditions, thus offering higher energy density than shredded or non-pelletized materials. It has been found that densifying and pressurizing the feedstock prior to it entering the gasifier allows the gasifier to operate at elevated pressures and also provides a feedstock with higher carbon density than shredded or non-pelletized material. The densified feedstock may be in the form of pellets. Optionally, such pellets may be cylindrical and may have a diameter substantially ranging from about 4 mm to 30 mm, in particular from about 4 mm to about 15 mm, more particularly being of a size of about 6 mm, about 8 mm or about 12 mm; and a length substantially ranging from about 8 mm to about 80 mm. Operating the gasifier at elevated pressures is beneficial since it produces a synthesis gas product at elevated pressures. This is useful because the conversion of the synthesis gas into a synthetic product also requires elevated pressures. Compared with a system operating at lower pressures, the present invention represents a considerably energy saving. This is because the pressure required to densify and pressurize the feedstock is considerably less than the additional pressure requirements for compression of synthesis gas produced at a lower gasifier pressure to levels required for conversion into a synthetic product. Thus, the net energy consumption is lower than in the prior art systems not utilizing a densified and pressurized feedstock, which makes the present invention more environmentally friendly.

[0086] The feedstock can also comprise coal, such as bituminous coal, sub-bituminous coal, lignite, peat and/or combinations thereof. In addition, mixtures between coal and the above-mentioned feedstock are possible.

The Feedstock

[0087] The feedstock is a carbon-containing solid fuel and can be any material which is suitable as a carbon-containing fuel, can be oxidized and can be used for gasification to yield synthesis gas.

[0088] The feedstock preferably comprises biomass and/or carbon-containing solid waste material is fed into the fluidized bed zone of the gasifier. The feedstock may be fed to the fluidized bed zone via a lock hopper system and feed screw conveyer at elevated pressures. The feed system (not shown in detail in Figure 1) may include a series of lock hoppers, star feeders and screw conveyers which are pressurized with CO_2. In certain embodiments, the CO_2 is separated from the raw syngas during downstream processing in methods known in the art. In certain embodiments, the separated CO_2 is reused as a pressurizing agent in the feed system to enable the feeding system to operate at the similar pressure as the gasifier.

[0089] Alternatively, any suitable apparatus for feeding the feedstock to the fluidized bed zone of the gasifier can be used.

[0090] Any suitable feedstock comprising biomass and/or carbon-containing solid waste material is suitable to be processed in the process of the present invention. In alternative embodiments the feedstock comprises biomass. In an alternative embodiment the feedstock comprises a carbon-containing solid waste material. In some embodiments, the feedstock comprises only biomass, in other embodiments only carbon-containing solid waste material and in further embodiments comprises a blend of biomass and carbon-containing solid waste material.

[0091] The process of the present invention is able to process homogenous and heterogeneous feedstocks. In certain embodiments the feedstock is a homogenous feedstock. In other embodiments the feedstock is a heterogeneous feedstock. The term "homogenous feedstock" refers to single-sourced material e.g., trees, agricultural residues, wood chips. "Heterogeneous feedstock" refers to multi-sourced materials e.g., materials such as wood residues from sawmills, textiles, paper, plastic, cardboard, hydrocarbon compounds and contaminants compounds.

[0092] Biomass refers to materials typically classed as biomass i.e., organic matter. Examples of biomass that may be used in the invention are wood and plants. Carbon-containing solid waste material is defined as any form of solid waste which comprises material that is carbon-containing. Examples of carbon-containing solid waste include wastes such as wood waste, agricultural waste, municipal solid waste (MSW), refuse derived fuels (RDF), dried sewage sludge and industrial waste. The above materials may be processed in the invention alone or in combination with one another in a blend. Preferred feedstocks include: RDF, MSW, waste wood (preferably untreated) and hard wood, all of which may be processed alone or in combination with one another. In particular, preferred feedstocks are selected from RDF alone, MSW alone, RDF and MSW blend, RDF with plastic, untreated wood and hard wood. Particularly preferred is the use of an RDF and MSW blend.

[0093] Various different feedstocks that comprise biomass and carbon-containing solid waste material, and in various different forms, are suitable feedstocks in the present process. Particularly preferred, however, is the use of a pelletized feedstock. Any suitable pelletizing method known in the art may be used. The pelletized feedstock is preferably pressurized in a pressurisation system prior to being supplied to the gasifier. The use of a pelletized material is not only favourable for gasification processes at elevated pressures but also provides a feedstock with higher bulk density than shredded or non-pelletized material. The use of pelletized flow material facilitates operation at high pressures achieving two main advantages, namely the higher feed density leads to lower CO_2 consumption which is advantageous for the process and improving the flowability of the feed material which can be important when using lock hopper gravity system for pressurization. Furthermore, there is a possibility to mix the moderate-to-high carbon content dust, removed from the process with pelletized feedstock, and thereby increasing the overall carbon conversion efficiency of the system. There is a possibility to premix minor amounts of additives including but not limited magnesium compounds to neutralize impurities such as chorine, fluorine and sulphur which are inherently present in pelletized carbon containing material.

The Plant

[0094] The features disclosed in the aforementioned sections "the gasifier", and "the feedstock", "the upstream process unit", especially the features relating to the process, equally apply to the plant according to the second aspect of the present invention and are combinable with the embodiments disclosed as follows.

[0095] In a second aspect, the present invention is directed to a process plant for converting feedstock comprising a carbon-containing solid fuel, such as biomass and/or carbon-containing solid waste material, to synthesis gas and downstream processing of the synthesis gas, the plant comprising:

a gasifier, the gasifier comprising a fluidized bed zone and a post-gasification zone and being configured to produce synthesis gas;

a downstream arrangement connected to said gasifier, the downstream arrangement being configured to obtain the synthesis gas produced in said gasifier;

a recycling arrangement arranged downstream of the gasifier and being configured to recycle at least a portion of the synthesis gas obtained in the downstream arrangement into at least one upstream process unit, such as the gasifier, the upstream process unit being arranged upstream of a position in the process from which said portion is recycled.

[0096] In certain embodiments, being combinable with all embodiments disclosed herein, a downstream arrangements individual units discloses in steps (b1) to (b5) or combinations thereof.

[0097] In certain embodiments, being combinable with all embodiments disclosed herein, a recycling arrangement includes a branching unit in which a portion of the synthesis gas for recycling is branched off. The branching unit is preferably arranged downstream of the unit in process step (b5). Furthermore the recycling arrangements includes pumps, conduits, mass flow controllers, valves, nozzles and/or further process components known to the skilled person for carrying out a recycling of a gas into an upstream process unit.

[0098] In certain embodiments, being combinable with all embodiments disclosed herein, the plant according to the second aspect of the present invention is configured to carry out the process according to the first aspect of the present invention.

Detailed Figure Description

[0099] A non-limiting embodiment of the process and the process plant of the present invention is shown in Figure 1.

[0100] In Figure 1, a pelletized biomass and/or carbon-containing solid waste material feedstock, produced in the pelletisation unit 202, is fed into the system via line 1, through lock hopper system 101 and via a connecting line to feed screw conveyer 102 at elevated pressures into a lower section of the fluidized bed zone, subzone A, of gasifier 103. Gasifier 103 has a fluidized bed zone, comprising subzones A to B, and a post-gasification zone comprising subzones C to E above (downstream from) the fluidized bed zone. The pelletized feedstock is introduced into the gasifier at subzone A, the socalled solid entry fluidized bed zone, in Figure 1.

[0101] Gasification agent comprising steam and oxygen is fed to gasifier 103 through lines 4 to 4d..

[0102] Although not shown in Figure 1, the gasification agent is introduced into the gasifier 103 via controlled flowrate through specialized multilayered nozzles. The form and amount of gasification agent introduced into the gasifier 103 will depend on the properties of the feedstock to be gasified. Typically the gasification agent is supplied to the gasifier so that the oxygen content in the gasifier is in the controlled range of 0.28 - 0.52 Nm^3/kg (daf) of the feedstock, of which at least about 20% and not greater than about 80% is supplied to the fluidized bed zone. In further embodiments, the gasification agent is supplied to the gasifier so that the oxygen content in the gasifier is in the controlled range of 0.35 - 0.45 Nm^3/kg (daf) of the feedstock, of which at least about 35% and not greater than about 65% is supplied to the fluidized bed zone. The temperature of the subzones is dependent on the ash softening temperature of the feedstock. The temperature of each subzone is achieved through the content, properties and amount of gasification agent (comprising at least oxygen and steam) added to the gasifier. An external heat source does not need to be used and in preferred embodiments is not used.

[0103] The feedstock is treated through the fluidized bed zone comprising sub-zones A and B and post-gasification zone comprising sub-zones C to E of the gasifier 103 by travelling and being treated through subzones A, B, C, D, E (with the bottom product being treated in sedimentation zone 201 and instead leaving via the bottom of the gasifier) for carrying out steps (a1) to (a5) as discussed herein before leaving the gasifier as a raw syngas product via line 8.

[0104] In subzone A, in which step (a1) is carried out, termed here as the solid entry fluidized bed zone, the pelletized feedstock is partially oxidized by the gasification agent comprising oxygen and steam. The gasification agent supply is controlled such that the average temperature of subzone B, in which step (a2) is carried out is within the range of 350-400°C below the ash softening temperature of the pelletized feedstock. Priorto carrying out the process the ash softening temperature of the pelletized feedstock is calculated and the supply of the gasification agent throughout the gasifier adjusted accordingly.

[0105] In subzone B of the fluidized bed zone, some of the feedstock in contact with hot fluid bed particles heats up and due to thermal expansion and physical abrasion decomposes on small pieces that after contacting the gasification agents decompose thermally, going through drying, pyrolysis and char-oxidation processes thereby producing heavy moderate-to-high carbon content residue that accumulates in the sedimentation subzone. The average temperature in the sedimentation zone is lower than the average temperature in subzone A and is between 400-500°C below the ash softening temperature of the feedstock. In the sedimentation subzone the bottoms product is treated with a gasification agent comprising steam (and CO_2).

[0106] The sedimentation zone, heavy solid carbonaceous residue settles down and leaves the gasifier via the bottom of the fluidized bed zone through discharge legs 5a and 5b. Over lines 303a and 303b, at least a part of the portion of synthesis gas, branched off at a branching unit (not shown in the figure), being arranged downstream of the acid gas removing unit 305, after the recovery is recycled into the process over discharge legs 5a and 5b providing a fluidization velocity ranging from 0.5 to 1.6 m/s depending on the bottom product physical properties. This arrangement is particularly advantageous to achieve the inventive effects as discussed earlier. Another part of the recycling portion can, at the same time be provided over lines 303e and 303d into subzone A, wherein in the latter case, the part of the recycling synthesis gas portion is provided over a return line 9 of a cyclone separator 104, the cyclone separator 104 being configured to remove dust from the raw synthesis gas leaving the gasifier 103, over line 8. Due to this recycling, a significant amount of carbon dioxide can be replaced, reducing the carbon footprint of the process. Furthermore, surprisingly the consumption of gasification agent oxygen entering the gasifier 103 through any of lines 4 to 4d can be significantly reduced by for example 2 Ma.-%. In addition, the carbon conversion efficiency and the cold gas efficiency are increased. Via lines connected to discharge legs 5a and 5b, the heavy residue is processed through lock hoppers 105, and then the via following lines to bottom product removal unit 106 before leaving via following lines to be used in the cement industry.

[0107] A partially oxidized produced gas containing low and high molecular weight hydrocarbons in the form of volatiles and heterocyclic compounds (e.g., phenol, cresol, quinoline, pyridine), together with light aromatic compounds (e.g., toluene, xylems, ethyl benzene), and light polyaromatic hydrocarbons (e.g., naphthalene, indene, biphenyl, anthracene), along with unreacted parts of the gasification agent, rises from the sedimentation zone to the upper most subzone of the fluidized bed zone, subzone B, termed here as the highly fluidized bed subzone.

[0108] Again, the supply of gasification agent to subzone B, in which step (a2) is carried out, is controlled by properties of the pelletized feedstock and the oxygen and steam gasification agent is supplied such that the average temperature in subzone B is higher than in subzone A and 250-350°C below the ash softening temperature of the feedstock. This condition provides an optimum temperature gradient along the reactor in the highly fluidized bed zone (subzone B) in which the produced gas from subzone B, in the form of heavy fly char loaded gas bubbles, is further decomposed and transformed thermally into a raw product gas with a higher fraction of lower molecular weight hydrocarbons.

[0109] In the fluidized bed zone, the pelletized carbon containing feedstock and the generated carbon content residue is contacted with fluidization agent for a time period of at least 8 minutes to ensure a high degree of completion for partial oxidation and homogenous and heterogenous thermal decomposition reactions.

[0110] The pelletized carbon containing feedstock in the fluidized bed zone gets partially oxidized and thermally decomposed to produce carbon monoxide and hydrogen, and volatiles of majorly lower molecular weight hydrocarbons together with intermediate species in the form of heterocyclic compounds, light aromatics, light polyaromatic hydrocarbons, unreacted part of the gasification agent, and entrained fly ash/char particles and then passes to the post-gasification zone, including subzones C to E, of the gasifier 103. The fly ash/char particles, still contain high carbon concentration have inorganic materials, such as alkali chlorides, metal oxides, etc. in the form salts. Fly ash/char particles are usually less than 200 microns in size, and therefore rise to the post-gasification zone. In the post-gasification zone, the partially oxidized material is contacted with gasification agent containing oxygen and steam (and sometimes CO_2) for a period of at least 7 s through three successive thermal subzones which are elaborated hereafter.

[0111] The thermochemically transformed material from the fluidized bed zone enters the post-gasification zone through subzone C, termed here as, heavily loaded solid fly ash/char subzone, wherein the temperature is adjusted through a controlled supply of gasification agent of steam and oxygen such that the average temperature is higher than in subzone C and is 200-300°C below the ash softening temperature of the feedstock. In subzone C, the carbon present in the fly char is further converted thermochemically in the presence of steam and oxygen to produce carbon monoxide and hydrogen, where, in parallel, the intermediate hydrocarbons produced in subzone C undergo cracking, thereby achieving a high carbon conversion efficiency.

[0112] The reformed and oxidized raw gas then enters subzone D, in which step (a3) is carried out, in the post-gasification zone, termed here as, low fly ash loaded subzone, where the steam and oxygen gasification agent supply is controlled such that the average temperature of subzone D is higher than in subzone C and 100-250°C below the ash softening temperature of the feedstock. Subzone D is characterized by further conversion of carbon present in the char particles and even further decomposition of intermediate hydrocarbons and tars present in the form of heterocyclic compounds, light aromatics, and light polyaromatic hydrocarbons. High temperatures in low fly ash loaded subzone (subzone D) allows for even better carbon conversion efficiency due to enhanced gasification reactions which improves the carbon conversion.

[0113] The raw syngas product from subzone D is passed through the topmost section of the gasifier, subzone E, where step (a5) is carried out, termed here a quench subzone. This subzone is still within the post-gasification zone of the gasifier 103. In subzone E, the raw syngas being cooled by about 50°C to about 100°C. In this subzone, the raw syngas is cooled using quench water or process condensate or a part of the recycled portion of the synthesis gas, which is sufficient to lower the average temperature below the ash softening point. The recycling of a portion of the recovered synthesis gas from branching unit 305, starting at line 303 can also take place into sub-zone E via line 303c. In this case, a cooling of sub-zone E takes place via the recycled synthesis gas. In such case, a further cooling step between line 303 and 303c (not shown in the figure) can be necessary.

[0114] This quenches the raw syngas thus freezing or quenching sticky particles formed in the higher temperatures and helps to minimize agglomeration problems or deposition of melted materials on the walls in the post-gasification zone and downstream units such as the cyclone separator 104 and the raw gas cooler 108.

[0115] The cooled raw syngas is then withdrawn from the gasifier 103 through line 8 and passed through a cyclone 104, in which approximately 95 % of the entrained dust is separated and recycled back through line 9 to the fluidized bed zone 116 of the gasifier 103. In general, recycling such particles which comprise of inorganic compounds coated with carbon can improve the overall carbon conversion efficiency by increasing the residence time of the fly ash/char particles in the gasifier.

[0116] The tar free syngas is withdrawn from the top of cyclone 104 and passes through raw gas cooler 108 to produce saturated steam. Part of the steam can be re-used in the process by going via a connecting line to superheater 115 and the superheated steam recycled to the gasifier 103 via line 12. The cooled syngas with a minimum temperature of 250 °C is subjected to further processing, enhancement, and purification including filtering in the fly-char dry based removal unit 109 through the connecting line, wherein the dust with the particle size greater than 5 microns is filtered and as a byproduct can be sent to either feedstock pelletizing unit 202 or the cement industry (through line 15b) via lock hopper 110 and dust removal unit 111. As shown in Figure 1, a part of the recycled synthesis gas portion of step (c) can also be used to clean the filter in the fly-char dry based removal unit 109, e.g. by pulsing. Through the further line to quench and scrubbing unit 112 where (a) the tar free syngas is saturated which is a favourable condition for downstream processing, e.g. CO shift and COS hydrolysis, and (b) the impurities such as hydrogen chloride are absorbed in alkali solution, while other impurities including H_2S, COS, NH_3, HCN, etc. are partially eliminated by adjusting the pH of the alkali solution. The sour water from the quench and scrubbing unit 112 is sent to the waste-water treatment unit 113 (through line 18b) for further stripping and treatment. The purified synthesis gas product is then obtained from the quench and scrubbing unit 112 and the clean synthesis gas is obtained in the CO shift and CO hydrolysis unit. Afterwards the clean synthesis gas proceeds to an acid gas removing unit 305 where a chemical or physical adsorption of CO_2 and H_2S and their removing from the syngas take place in order to provide clean synthesis gas for further processing. After the acid gas removing unit, a portion of the clean synthesis gas can be branched off for recycling to at least one upstream unit over lines 303 to 303e. where portions of it are branched off, the branched off portions either being led over line 303 as a recycling synthesis gas, to further processing in order to produce biofuel, such as methanol, gasoline and jet fuel) or to a further sulfur removal unit and CO2 polishing.

[0117] The gasification agent is introduced into the gasifier at various entry points throughout the fluidized bed zone and the post-gasification zone. The optimized conditions throughout the gasifier are aided through the use of specialized, multilayered nozzles (not shown in Figure 1) that introduce the gasification agent into the gasifier at an acute angle relative to a horizontal plane. The gasification agent is supplied in sufficient quantity and content to partially oxidize and thermochemically decompose the pelletized feedstock to high quality, tar free syngas. As will be understood by the person skilled in the art, the conditions within the gasifier may also be further optimized based on thermochemical properties of the pelletized feedstock, such as fixed carbon content, heating value, metal content and other impurity levels etc.

[0118] The order of the steps of the processes described herein is exemplary (unless a certain order is necessitated through the explicit wording of the steps), but the steps may be carried out in any suitable order, or simultaneously where appropriate. Additionally, steps may be added or substituted in, or individual steps may be deleted from any of the processes without departing from the scope of the subject matter described herein.

[0119] It will be understood that the description of preferred embodiments herein is given by way of example only and that various modifications may be made by those skilled in the art. What has been described above includes examples of one or more embodiments. It is, of course, not possible to describe every conceivable modification and alteration of the above process and apparatus for purposes of describing the aforementioned aspects, but one of ordinary skill in the art can recognize that many further modifications and permutations of various aspects are possible. Accordingly, the described aspects are intended to embrace all such alterations, modifications, and variations that fall within the scope of the appended claims.

Claims

1. A process for converting feedstock comprising a carbon-containing solid fuel, such as biomass and/or carbon-containing solid waste material, to synthesis gas and downstream processing of the synthesis gas, the process comprising the following steps:

(a) converting the feedstock in a gasifier, the gasifier comprising a fluidized bed zone and a post-gasification zone, to produce synthesis gas;
(b) obtaining the synthesis gas produced in step (a) downstream of the gasifier;
(c) recycling a portion of the synthesis gas of step (b) into at least one upstream process unit, such as the gasifier, the upstream process unit being arranged upstream of a position in the process from which said portion is recycled.

2. The process according to any one of the claim 1, wherein the at least one upstream process unit comprises the gasifier.

3. The process according to claim 2, wherein step (c) comprises at least one of the sub-steps:

(c1) recycling the portion of the synthesis gas of step (b) into the fluidized bed zone; and/or
(c2) recycling the portion of the synthesis gas of step (b) into the post-gasification zone.

4. The process according to any one of the preceding claims, wherein the fluidized bed zone comprises the following subzones, starting from the lowest position of subzone A with respect to the earth's surface:

- Subzone A in which a step (a1) of contacting the feedstock with a gasification agent comprising steam and oxygen is carried out, at an average temperature in the range of between about 350-400°C below the ash softening temperature of the feedstock, to partially oxidize the feedstock; and
- Subzone B, being arranged on top of subzone A, in which a step (a2) of contacting the partially oxidized product produced in step (a1) with a gasification agent comprising steam and oxygen is carried out, at a higher average temperature than in step (a1) and at an average temperature in the range of between about 250-350°C below the ash softening temperature of the feedstock;

and/or wherein the post-gasification zone comprises the following subzones starting from the lowest position of subzone C with respect to the earth's surface:

- Subzone C, being arranged on top the fluidized bed zone, in which step (a3) of contacting at least a portion of the product produced in the fluidized bed zone, in particular in step (a2), with a gasification agent comprising steam and oxygen is carried out, at a higher average temperature than in the fluidized bed zone, in particular than in step (a2), the average temperature being between about 200-300°C below the ash softening temperature of the feedstock; and
- Subzone D, being arranged on top of subzone C, in which step (a4) of contacting at least a portion of the product produced in step (a3) with a gasification agent comprising steam and oxygen is carried out at a higher average temperature than in step (a3), the average temperature being between about 100 to about 250°C below the ash softening temperature of the feedstock, to produce the synthesis gas.

5. The process according to claim 4, wherein at least a part of the portion of step (c) is recycled and introduced into subzone A.

6. The process according to claim 4 or 5, wherein the post-gasification zone further comprises:

- Subzone E, arranged on top of subzone D, in which step (a5) of cooling at least a portion of the product produced in step (a4) to an average temperature lower than in step (a4) is carried out, the synthesis gas being cooled by about 50°C to about 100°C in terms of the average temperature within subzone E, optionally compared to the average temperature of subzone D; and
- wherein at least a part of the synthesis gas portion in step (c) is recycled into subzone E for cooling.

7. The process according to any one of the preceding claims, wherein step (b) comprises the sub-steps of:

(b1) cooling the synthesis gas produced in step (a) by a raw gas cooler downstream of the gasifier to obtain a cooled synthesis gas;
(b2) filtering the cooled synthesis gas obtained in step (b1) by a filter unit to obtain a filtered synthesis gas;
(b3) cleaning the filtered synthesis gas obtained in step (b2) by a washing unit to obtain a purified synthesis gas;
(b4) removing carbon dioxide from purified synthesis gas obtained in step (b3) using a CO shift and CO hydrolysis unit to obtain clean synthesis gas.

8. The process according to claim 7, wherein the synthesis gas of which a portion is recycled in step (c) is selected from the any of the synthesis gases obtained in any of steps (b1) to (b4) or a combination thereof.

9. The process according to any one of the preceding claims, the gasifier further comprising a sedimentation zone with at least one discharge leg, the sedimentation zone being arranged below the fluidized bed zone with respect to the earth's surface, wherein

- heavy solid residues migrating in a downwards direction within the gasifier and being obtained in the fluidized bed zone are discharged from the at least discharge leg of the sedimentation zone; and
- at least a part of the synthesis gas portion of step (c) is recycled to the sedimentation zone, in particular to the at least one discharge leg.

10. The process according to any one of the preceding claims, wherein a cyclone separator, in which fine solids are separated from the synthesis gas, is arranged downstream of the gasifier.

11. The process according to claim 10, wherein the solids are recycled into the gasifier by a return line which connects said cyclone separator and the gasifier; and wherein the at least one upstream unit comprises the return line at least a part of the synthesis gas portion of step (c) is recycled and introduced into the return line.

12. The process according to claim 10 or 11, wherein an intermediate cooling unit is arranged downstream and outside of the gasifier and upstream of the cyclone separator, wherein the at least one upstream unit comprises the intermediate cooling unit and at least another part of the synthesis gas portion of step (c) is recycled and introduced into the intermediate cooling unit; and wherein the cyclone separator is a cyclone candle filter unit.

13. The process according to any one of the preceding claims, wherein the synthesis gas portion in step (c) is at least

2 Ma.-% up to 30 Ma.-% in relation to the total mass of the synthesis gas obtained in step (b).

14. The process according to any one of the preceding claims, further comprising the step of densifying, in particular pelletizing, the feedstock prior to an introduction into the gasifier.

15. A process plant for converting feedstock comprising a carbon-containing solid fuel, such as biomass and/or carbon-containing solid waste material, to synthesis gas and downstream processing of the synthesis gas, the plant comprising:

- a gasifier, the gasifier comprising a fluidized bed zone and a post-gasification zone and being configured to produce synthesis gas;
- a downstream arrangement connected to said gasifier, the downstream arrangement being configured to obtain the synthesis gas produced in said gasifier;
- a recycling arrangement arranged downstream of the gasifier and being configured to recycle at least a portion of the synthesis gas obtained in the downstream arrangement into at least one upstream process unit, such as the gasifier, the upstream process unit being arranged upstream of a position in the process from which said portion is recycled.

Amended claims in accordance with Rule 137(2) EPC.

1. A process for converting feedstock comprising a carbon-containing solid fuel, such as biomass and/or carbon-containing solid waste material, to synthesis gas and downstream processing of the synthesis gas, the process comprising the following steps:

(a) converting the feedstock in a gasifier (103), the gasifier (103) comprising a fluidized bed zone (116) and a post-gasification zone, to produce synthesis gas;
(b) obtaining the synthesis gas produced in step (a) downstream of the gasifier; and
(c) recycling a portion of the synthesis gas of step (b) into at least one upstream process unit, the at least one upstream process unit comprising the gasifier (103), the upstream process unit being arranged upstream of a position in the process from which said portion is recycled, wherein
the synthesis gas portion in step (c) is at least 2 Ma.-% up to 30 Ma.-% in relation to the total mass of the synthesis gas obtained in step (b).

2. The process according to claim 1, wherein step (c) comprises at least one of the sub-steps:

(c1) recycling the portion of the synthesis gas of step (b) into the fluidized bed zone (116); and/or
(c2) recycling the portion of the synthesis gas of step (b) into the post-gasification zone.

3. The process according to claim 1 or claim 2, wherein the fluidized bed zone (116) comprises the following subzones, starting from the lowest position of subzone A with respect to the earth's surface:

- Subzone A in which a step (a1) of contacting the feedstock with a gasification agent comprising steam and oxygen is carried out, at an average temperature in the range of between about 350-400°C below the ash softening temperature of the feedstock, to partially oxidize the feedstock; and
- Subzone B, being arranged on top of subzone A, in which a step (a2) of contacting the partially oxidized product produced in step (a1) with a gasification agent comprising steam and oxygen is carried out, at a higher average temperature than in step (a1) and at an average temperature in the range of between about 250-350°C below the ash softening temperature of the feedstock;

and/or wherein the post-gasification zone comprises the following subzones starting from the lowest position of subzone C with respect to the earth's surface:

- Subzone C, being arranged on top the fluidized bed zone (116), in which step (a3) of contacting at least a portion of the product produced in the fluidized bed zone (116), in particular in step (a2), with a gasification agent comprising steam and oxygen is carried out, at a higher average temperature than in the fluidized bed zone (116), in particular than in step (a2), the average temperature being between about 200-300°C below the ash softening temperature of the feedstock; and

- Subzone D, being arranged on top of subzone C, in which step (a4) of contacting at least a portion of the product produced in step (a3) with a gasification agent comprising steam and oxygen is carried out at a higher average temperature than in step (a3), the average temperature being between about 100 to about 250°C below the ash softening temperature of the feedstock, to produce the synthesis gas.

4. The process according to claim 3, wherein at least a part of the portion of step (c) is recycled and introduced into subzone A.

5. The process according to claim 3 or 4, wherein the post-gasification zone further comprises:

- Subzone E, arranged on top of subzone D, in which step (a5) of cooling at least a portion of the product produced in step (a4) to an average temperature lower than in step (a4) is carried out, the synthesis gas being cooled by about 50°C to about 100°C in terms of the average temperature within subzone E, optionally compared to the average temperature of subzone D; and
- wherein at least a part of the synthesis gas portion in step (c) is recycled into subzone E for cooling.

6. The process according to any one of the preceding claims, wherein step (b) comprises the sub-steps of:

(b1) cooling the synthesis gas produced in step (a) by a raw gas cooler (108) downstream of the gasifier (103) to obtain a cooled synthesis gas;
(b2) filtering the cooled synthesis gas obtained in step (b1) by a filter unit to obtain a filtered synthesis gas;
(b3) cleaning the filtered synthesis gas obtained in step (b2) by a washing unit to obtain a purified synthesis gas;
(b4) removing carbon dioxide from purified synthesis gas obtained in step (b3) using a CO shift and CO hydrolysis unit to obtain clean synthesis gas.

7. The process according to claim 6, wherein the synthesis gas of which a portion is recycled in step (c) is selected from the any of the synthesis gases obtained in any of steps (b1) to (b4) or a combination thereof.

8. The process according to any one of the preceding claims, the gasifier (103) further comprising a sedimentation zone with at least one discharge leg, the sedimentation zone being arranged below the fluidized bed zone (116) with respect to the earth's surface, wherein

- heavy solid residues migrating in a downwards direction within the gasifier (103) and being obtained in the fluidized bed zone (116) are discharged from the at least discharge leg of the sedimentation zone; and
- at least a part of the synthesis gas portion of step (c) is recycled to the sedimentation zone, in particular to the at least one discharge leg.

9. The process according to any one of the preceding claims, wherein a cyclone separator, in which fine solids are separated from the synthesis gas, is arranged downstream of the gasifier (103).

10. The process according to claim 9, wherein the solids are recycled into the gasifier (103) by a return line which connects said cyclone separator and the gasifier (103); and wherein the at least one upstream unit comprises the return line at least a part of the synthesis gas portion of step (c) is recycled and introduced into the return line.

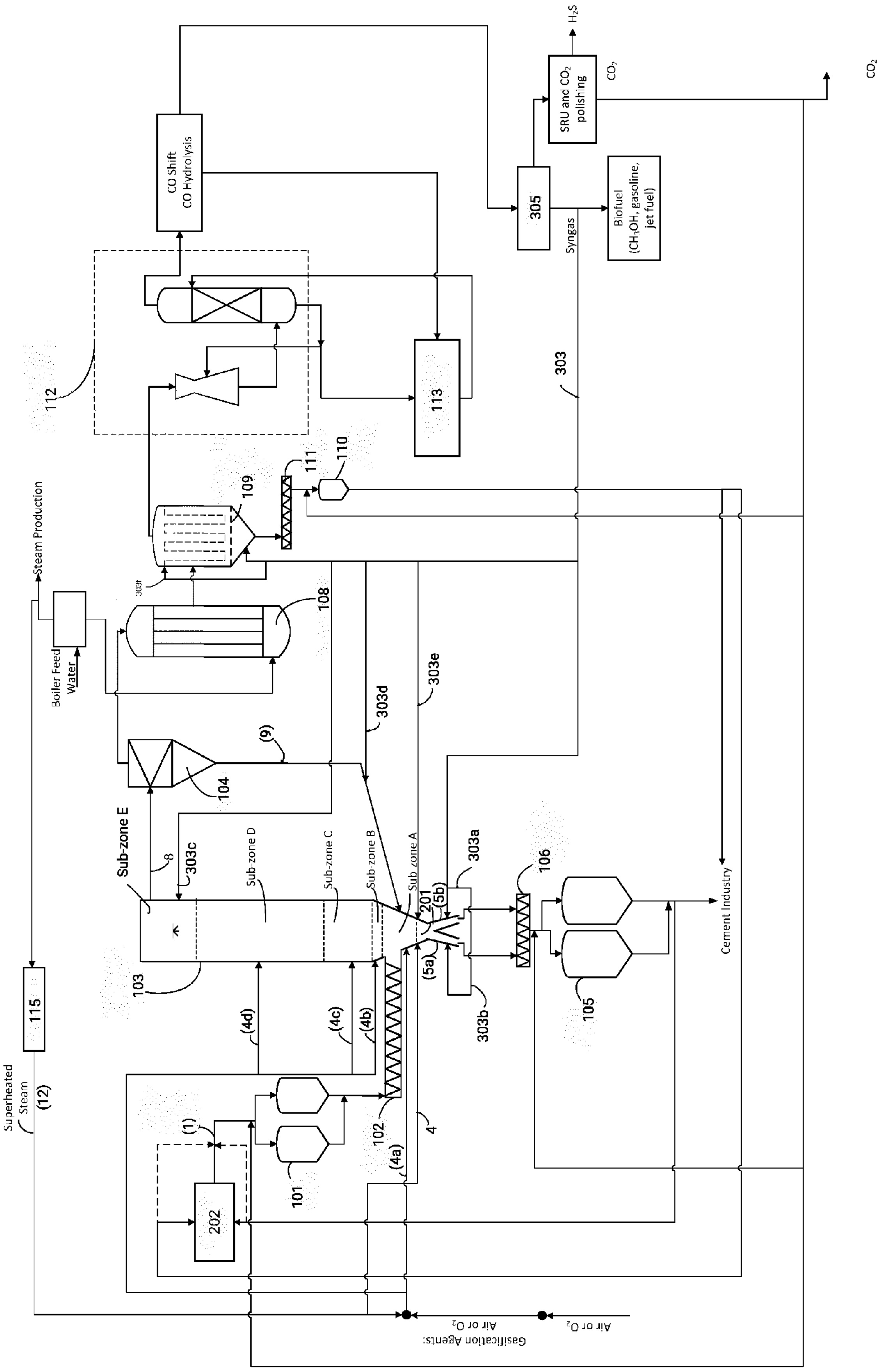
11. The process according to claim 9or 10, wherein an intermediate cooling unit is arranged downstream and outside of the gasifier (103) and upstream of the cyclone separator, wherein the at least one upstream unit comprises the intermediate cooling unit and at least another part of the synthesis gas portion of step (c) is recycled and introduced into the intermediate cooling unit; and wherein the cyclone separator is a cyclone candle filter unit.

12. The process according to any one of the preceding claims, wherein the synthesis gas portion in step (c) is about 5 Ma.-% to about15 Ma.-% in relation to the total mass of the synthesis gas obtained in step (b).

13. The process according to any one of the preceding claims, further comprising the step of densifying, in particular pelletizing, the feedstock prior to an introduction into the gasifier (103).

14. A process plant for converting feedstock comprising a carbon-containing solid fuel, such as biomass and/or carbon-containing solid waste material, to synthesis gas and downstream processing of the synthesis gas, the plant comprising:

- a gasifier (103), the gasifier (103) comprising a fluidized bed zone (116) and a post-gasification zone and being configured to produce synthesis gas;
- a downstream arrangement connected to said gasifier (103), the downstream arrangement being configured to obtain the synthesis gas produced in said gasifier; and
- a recycling arrangement arranged downstream of the gasifier (103) and being configured to recycle at least a portion of the synthesis gas obtained in the downstream arrangement into at least one upstream process unit, as the at least one upstream process unit comprising the gasifier (103), the upstream process unit being arranged upstream of a position in the process from which said portion is recycled, wherein the synthesis gas portion recycled is at least 2 Ma.-% up to 30 Ma.-% in relation to the total mass of the synthesis gas obtained in the downstream arrangement.


H$_2$S
SRU and CO$_2$ polishing
CO$_2$
CO$_2$
CO Shift
CO Hydrolysis
305
Syngas
Biofuel (CH$_3$OH, gasoline, jet fuel)
112
113
303
110
111
109
Steam Production
303f
108
Boiler Feed Water
303d
303e
(9)
104
Sub-zone E
8
303c
Sub-zone D
Sub-zone C
Sub-zone B
Sub-zone A
201
(5b)
(5a)
303a
106
303b
105
Cement Industry
103
115
Superheated Steam
(12)
(4d)
(4c)
(4b)
102
4
(4a)
(1)
101
202
Gasification Agents:
Air or O$_2$
Air or O$_2$

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EUROPEAN SEARCH REPORT

Application Number
EP 22 17 9259

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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	29 November 2022	Lachmann, Richard

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