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(12) **EUROPEAN PATENT APPLICATION**

(54) **GASIFIER AND GASIFICATION REACTOR WITH MULTIPLE COMBINED REACTION ZONES**

(57)   The invention refers to a gasifier (1) for converting feedstock material into product gas, comprising a container (11) for receiving feedstock material, a gasification reactor (10) arranged downstream and extending in a longitudinal direction (L), a feeding unit (13) for feeding the feedstock material through the gasification reactor (10) in the longitudinal direction (L). The gasification reactor (10) has a first inlet (7.1, 8.1) for supplying a gasification agent thereby defining a first reaction zone (5.1), having an extension (Δx_1) in the longitudinal direction (L).

The invention suggests, that the gasification reactor (10) further has a downstream second inlet (7.2, 8.2) for supplying the gasification agent thereby defining a second reaction zone, having an extension (Δx_2), wherein the second inlet (7.2, 8.2) is arranged at a distance (x_1) from the first inlet (7.1, 8.1), which is preferably defined as $x_1 \leq \frac{\Delta x_1 + \Delta x_2}{2}$, such that the first reaction zone (5.1) partly overlaps the second reaction zone (5.2).
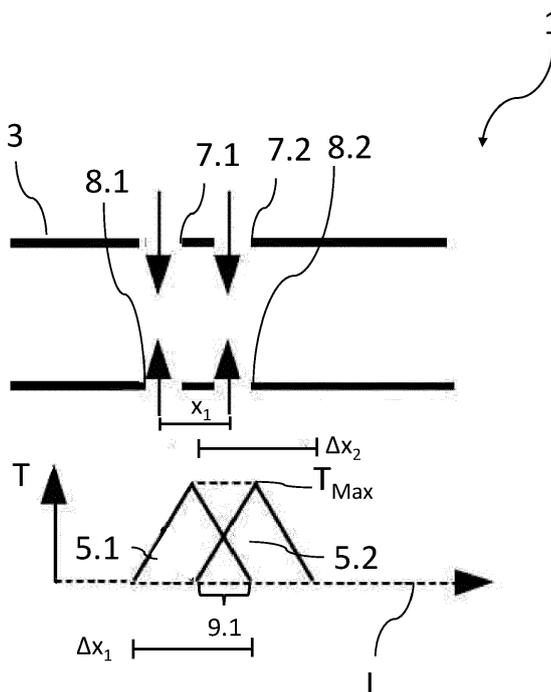
FIG. 2

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Description

[0001]   The invention relates to a gasifier and a and gasification reactor for converting carbonaceous feedstock material into a product gas, comprising: a container configured to receive a feedstock material, a gasification reactor extending in a longitudinal direction and arranged downstream the container, and a feeding unit for feeding the feedstock material from the container through the gasification reactor in the longitudinal direction.

[0002]   Gasification of biomass, which is referred herein as "gasification process", is performed by a number of sub-processes for converting a biomass feedstock into a product gas. These sub-processes include:

1) The dehydration or drying process occurs at around 100 °C. Typically, the resulting steam is mixed into the gas flow and may be involved with subsequent chemical reactions, notably the water-gas reaction if the temperature is sufficiently high.

2) The pyrolysis (or devolatilization) process occurs at around 200-300 °C. Volatiles are released and char is produced, resulting in up to 70% weight loss for coal. The process is dependent on the properties of the carbonaceous material and determines the structure and composition of the char, which will then undergo gasification reactions.

3) The combustion process occurs as the volatile products and some of the char react with oxygen to primarily form carbon dioxide and small amounts of carbon monoxide, which provides heat for the subsequent gasification reactions. Letting C represent a carbon-containing organic compound, the basic reaction here is $C + O_2 \rightarrow CO_2$.

4) The gasification process occurs as the char reacts with steam and carbon dioxide to produce carbon monoxide and hydrogen, via the reactions $C + H_2O \rightarrow H_2 + CO$ and $C + CO_2 \rightarrow 2\,CO$.

5) In addition, the reversible gas phase water-gas shift reaction reaches equilibrium 5) very fast at the temperatures in a gasifier. This balances the concentrations of carbon monoxide, steam, carbon dioxide and hydrogen. $CO + H_2O$ <-> $H_2 + CO_2$.

[0003]   In essence, a limited amount of oxygen provided by a gasification agent is introduced into the reactor to allow some of the organic material to be "burned" to produce carbon dioxide and energy, which drives a second reaction that converts further organic material to hydrogen and additional carbon dioxide. The gasification agent can be either air, pure oxygen or a mixture of several gasification agents.

[0004]   The combustible products of gasification are in particular carbon monoxide (CO) and hydrogen (H_2), with only a minor amount of the carbon completely oxidized to carbon dioxide (CO_2) and water. The heat released by partial oxidation provides most of the energy needed to break up the chemical bonds in the feedstock material, to drive the other endothermic sub-processes in the gasification reaction, and to increase the temperature of the final gasification products.

[0005]   Biomass feedstock used for the gasification process may comprise a broad range of different kinds of biomaterials, such as forest and agricultural residues, wood or waste from wood and waste from the food industry, algae, etc. The use of different kinds of biomass results in different challenges and solutions for e.g. pretreatment and feeding of the biomass, for operation of the gasifier, and for cleaning of the produced product gas. Since the biomass varies in size distribution (eg, stalks, stems), a bulk density, and a resulting volumetric energy density, an additional mechanical treatment may be necessary, as for example size reduction and compaction of raw biomass is adjusting the feedstock to the requirements of the conversion process regarding size, homogeneity, and physical properties of the fuel.

[0006]   The process described above may also be referred as an autothermal or direct gasification process. In the autothermal gasification process, during oxidation the volatile products and some of the char react with limited oxygen in the gasification agent to form carbon dioxide (CO2), carbon monoxide (CO), and in doing so provide the heat needed for subsequent pyrolysis and further reactions for gasifying the pyrolysis products. Pyrolysis starts as the feedstock is exposed to rising temperature in the gasifier due to the partial oxidation. Devolatization and breaking of the weaker chemical bonds occurs, releasing volatile gases such as tar vapors, methane, and hydrogen, along with producing a high molecular weight char, which will undergo further reactions for gasifying. The reactions for gasifying the pyrolysis products into product gas include the combustion of the volatile products contained in the pyrolysis products and some of the char, which react with oxygen to form carbon dioxide primarily and small amounts of carbon monoxide, which provides heat for the subsequent reactions. The gasification process further includes the reaction for gasifying char with steam and carbon dioxide to produce carbon monoxide and hydrogen, via the reactions $C + H_2O \rightarrow H_2 + CO$ and $C + CO_2 \rightarrow 2\,CO$. Further reactions occur when the formed carbon monoxide and residual water from the organic material react to form methane and excess carbon dioxide. In addition, further reactions occurs more abundantly in reactors that increase the residence time of the reactive gases and organic materials, as well as heat and pressure.

[0007]   The chemical reactions of the gasification process can progress depend to different extends on the gasification conditions, like temperature and pressure, and the feedstock used.

[0008]   In biomass gasification process, the formation of tar is a main problem. Tar is considered as all organics with a molecular weight larger than that of benzene. Tar condensation at lower temperatures can cause clogging or blockage

of pipes, filters, catalyst units, or engines. Thus, one of the main problems in improving the industrial viability of biomass gasification process is related to the presence of tar in the product gas. Tar is a quite complex mixture of different condensable hydrocarbons including one and multiple ring aromatics as well as oxygen containing hydrocarbons. However, the reforming and cracking reactions require high temperatures, above 1200°C, to be efficient due to high activation energies; in most cases, these are greater than 250-350 kJ/mol.

[0009] In conventional fixed bed gasifiers the combustion process - and therefore all reactions driven by the combustion process - is maintained by means of oxygen provided by a gasification agent, which enters through one or several openings at a single position in the direction of the material flow. At this position, the oxygen agent is used to create a reaction zone of high temperature, where subsequently the processes of drying, pyrolysis, combustion and gasification occur.

[0010] More recent developments use a sequence of several reactors or reaction zones in order to separate at least to some extend the different reactions from each other, so that the ideal conditions for each reaction may be provided in each corresponding reaction zone. Here the term "separated" can be defined by a decease of the temperature up to a minimum between said zones.

[0011] One of the drawbacks of gasifiers of the aforementioned type is that the temperature profile along the direction of the material flow is very uneven, and thus the maximum temperature is reached only in a small portion of the gasification reactor. Further, as the material reaches a minimum temperature between the two or more reaction zones, the material may solidify and thus creates a material similar to or identical to coke. This will severely compromise gasifier operation. Furthermore, the construction of several separated reaction zones increases the complexity and the size of the gasifier, resulting in expensive and large gasifier plants.

[0012] Therefore, it was an object of the present invention to solve at least one of the drawbacks known from the prior art. In particular, it was an object of the present invention on the one hand to increase the power capability of a gasifier having a given size and on the other hand to decrease the size of a gasifier providing a given power respectively.

[0013] The present invention solves the initially mentioned object by suggesting a gasifier according to claim 1. In particular, the present invention suggests, that the gasification reactor has a first inlet for supplying a gasification agent comprising oxygen thereby defining a first reaction zone for the gasification process, the first reaction zone having an extension Δx_1, in the longitudinal direction. The gasification reactor according to the invention further has a downstream second inlet for supplying the gasification agent thereby defining a second reaction zone for the gasification process, wherein the second reaction zone has an extension Δx_2 in the longitudinal direction. The second inlet is arranged at a distance x_1 from the first inlet, which is preferably defined as $x_1 \leq \frac{\Delta x_1 + \Delta x_2}{2}$, such that the first reaction zone at least partly overlaps the second reaction zone. Thus, the distance between the inlets is sufficiently small and the inlets are arranged so close that they form a combined reaction zone without a significant decrease of the temperature between the zones. In particular, the maximum temperature in the first reaction zone is defined by T_1 and the maximum temperature in the second reaction zone is defined by T_2, the distance between the first inlet and the second inlet is chosen, such that the minimum temperature T_{Min} is defined by the formula $T_{Min} \geq \frac{T_1 + T_2}{2}$, preferably by $T_{Min} \geq \frac{4 \cdot (T_1 + T_2)}{5}$. In other words, the combined reaction zone is characterized by the fact, that the temperature in the combined reaction zone is first increasing and then approximately constant, without showing significant temperature minima. It shall be understood, that the first reaction zone overlaps the second reaction zone in such a manner that the reactions in the first and second reaction zone are not separated from each other but instead advantageously interact and join each other. In other words, different reactions, e.g. oxidation and reduction, cannot be clearly associated to one of the reaction zones but instead occur over a longer distance with a more constant temperature profile.

[0014] Thus, the zone in which oxidation occurs is not separated from the zone, in which pyrolysis occur. Preferably, none of the reaction zones has the purpose to drive one particular process, like for instance pyrolysis, and vice versa it is not possible to attribute to any of the processes one particular reaction zone. Instead, all sub-processes may run in the first reaction zone and in the second reaction zone. As described above, due to the increased residence time further reactions subsequent gasifying char with steam and carbon dioxide to produce carbon monoxide and hydrogen may occur when the formed carbon monoxide and residual water from the organic material react to form methane and excess carbon dioxide that will decrease the formation of tar and increase the efficiency.

[0015] In general, due to the at least two reaction zones the amount of feedstock material that has not yet been converted into a pyrolysis products or a product gas in the first reaction zone will enter the second reaction zone. By the first reaction zone overlapping the second reaction zone, the second reaction zone makes use of the increased temperature within the gasification reactor provided by the first reaction zone. As such, the temperature of the feedstock material entering the second reaction zone is higher when compared to the feedstock material entering the first reaction zone. Since, the feedstock material entering of the second reaction zone is pre-heated, the feedstock material can be faster

heated to the desired temperature, e.g. T_{Max} or even higher and hold at close to the desired temperature at a longer period. Thus, the thermal energy in the gasification reactor is increased due to the holding time without significantly increasing the temperature. Thereby sufficient activation energies required for the reforming and cracking reactions of tar are provided. Thus, the quality of the product gas is improved and subsequent cleaning processes may be reduced or even avoided. Further, by having a first reaction zone and a second reaction zone each providing thermal energy for pyrolysis and gasifying the pyrolysis products, the power of the gasifier is increased. This is reasoned by the fact, that the amount of feedstock material that can be converted is not limit to the extension of a single reaction zone, in which the temperature may be sufficiently high for the gasifying the pyrolysis products including e.g. the reaction of the subsequently formed carbon monoxide or carbon dioxide with residual water. It will be understood, that by having two reaction zones the velocity of the feedstock material is not only doubled and instead even higher. This is reasoned by the enlarged zone in which the temperature can be hold sufficiently high for the different sub-processes of the gasification process.

[0016] In consequence, the different sub-processes will not be neatly separated from each other. In a long tube with a series of set of inlets instead, the volatiles during pyrolysis will be dissipated at the beginning, and at the end only reduction reactions of the combustion gases formed during oxidation will occur, so there is a much better separation of the different sub-processes.

[0017] The term "overlapping" in the context of the invention means, that the temperature which results by the introduction of the gasification agent by the first inlet will not fall significantly, in particular not to the temperature at the very beginning of the gasification reactor, but instead increase again due to the introduction of the gasification agent introduced by the second inlet. In particular, the temperature remains above a minimum temperature T_{Min} that is defined by the formula $T_{Min} \geq \frac{T_1 + T_2}{2}$, preferably by $T_{Min} \geq \frac{4 \cdot (T_1 + T_2)}{5}$. Preferably, the temperature between the overlapping reaction zones will not fall at all. Further, not only the temperatures somehow overlap each other, but also the reactions or sub-processes occurring in the reaction zone.

[0018] It will be understood, that a set of inlets arranged at a defined position along the longitudinal axis, which is configured for supplying the gasification agent in different radial directions, can also provide the inlet according to the invention. The set of inlets can comprise any number of inlets depending on the size of the gasification reactor. The number of inlets is preferably distributed in a circumferential direction and in particular uniform distributed.

[0019] The extension of the gasification reactor in the longitudinal direction is preferably larger than the extension in the perpendicular directions.

[0020] Preferably, the gasification reactor is configured for partial oxidation of the feedstock material in the first and second reaction zone under supply of the gasification agent to provide a heat amount and for pyrolysis of the feedstock material under supply of said heat amount. By combining the oxidation and the pyrolysis of the feedstock material in said first and second reaction zone, the pyrolysis efficiency is increased by directly participating from the heat amount resulting from the oxidation process. Further, the remaining feedstock material that has not been converted into the pyrolysis product can react with the oxygen in the gasification agent to maintain the required heat.

[0021] In a preferred embodiment, the gasification reactor further has a number i of inlets downstream the first inlet and the second inlet for supplying gasification agent, thereby defining a number i of reaction zones each having an extension Δx_i in the longitudinal direction, wherein starting from the second inlet each inlet is arranged at a distance x_i in the longitudinal direction from the respective upstream adjacent inlet, which is preferably defined as $x_i \leq \frac{\Delta x_{i-1} + \Delta x_i}{2}$. Thus, each reaction zone at least partly overlaps the upstream adjacent reaction zone. By providing a multitude of reaction zones, which are placed so close to each other, that together they form one single large reaction zone, the temperature in the gasification reactor is first increasing and then approximately constant, without significant temperature minima. The multitude of zones serves for the creation of one large reaction zone with an even temperature profile.

[0022] Preferably, the inlets are uniform distributed in the in the longitudinal direction having an equal distances x_i from the respective upstream adjacent reaction zone. Thus, the distance between the inlets required to hold the temperature in the subsequent reaction zones in a desired temperature range is simple to calculate.

[0023] In particular, the gasification reactor is configured for pyrolysis of the feedstock material in the reaction zone at a temperature between 300°C and 600°C to form a pyrolysis product and for gasifying the pyrolysis product in the reaction zone at a temperature between 700°C and 1500°C to form a product gas. When gasifying the pyrolysis product, the pyrolysis products react further at relatively high temperatures between 700°C and 1500°C with the gasification agent or product gases by numerous chemical reactions as described above. It shall be understood, that the gasification reactor configured for pyrolysis of the feedstock material in the reaction zone at a temperature between 300°C and 600°C is adapted to withstand that temperatures by an appropriate choice of materials and joining processes.

[0024] Preferably, the container and/or the gasification reactor is configured for heating the feedstock material up to an evaporation temperature above 100°C to evaporate water contained in the feedstock material. Thus, any or at least

a part of the free water content of the feedstock material evaporates, leaving dry feedstock material suitable for the subsequent sub-processes. As such, the gasification reactor is preferably equipped wit a heater for heating the feedstock material up to an evaporation temperature above 100°C.

[0025] In a preferred embodiment, the gasification reactor has a frustoconical end portion, in particular arranged in an area downstream the feeding unit. When supplying the gasification agent at high velocities via the inlets, there is a risk that the feedstock material is carried away, if the velocity of the gas is too high.

[0026] Preferably, at least one inlet is defined by a first inlet and a second inlet arranged opposite the first inlet. Thus, the gasification agent is introduced more uniform into the gasification reactor.

[0027] Further preferred, at least the first inlet has the form of a slit, wherein the slit preferably extends perpendicular to the longitudinal direction. In particular the first inlet, arranged subsequently downstream of the container, may be obstructed by the feedstock material and ash from partial oxidation. By having at least one inlet formed as a slit, the obstructions are reduced.

[0028] In a preferred embodiment, the gasification reactor has a supply for the gasification agent, and the gasifier further has a control unit being in signal communication with the supply for controlling the amount of gasification agent provided by the supply at least to the first and second inlet. Thus, the supply of the gasification agent may be selectively controlled thereby in accordance with the feedstock material or other process conditions. It will be understood, that the supply is directly or indirectly in fluid connection with each of the inlets.

[0029] Preferably, the gasification reactor has at least one detection unit configured to detect a temperature and/or a pressure at least at one of the inlets and/or in at least one of the reaction zones. Thus, the control unit may control the supply in accordance with the detected temperature and/or pressure to reach a predefined temperature or pressure.

[0030] In a further preferred embodiment, the gasification reactor has a shell enclosing the at least one inlet, which is in fluid communication with the supply for the gasification agent. Thus, the supply is indirectly in fluid communication with the inlets via the shell. The shell provides a uniform pressure control of the inlets and a uniform pressure supply. Further, the shell protects the inlets from dirt and dust from the environment.

[0031] It is preferred, that the gasification reactor has a cleaning mechanism for automatically cleaning at least the first inlet without interrupting gasifier. The cleaning mechanism may comprise a nozzle in fluid communication with the supply for cleaning the inlet by means of pressurized air.

[0032] As described above, the invention relates in a first aspect to a gasifier.

[0033] In a second aspect, the invention relates to a gasification reactor for gasification of a feedstock material in a gasifier, in particular in a gasifier according to the first aspect of the invention. The gasification reactor according to the second aspect extends in a longitudinal direction and is configured to be arranged downstream a container of the gasifier and to cooperate with a feeding unit for feeding the feedstock material from the container through the gasification reactor in the longitudinal direction.

[0034] The gasification reactor solves the initially mentioned object by a first inlet for supplying a gasification agent comprising oxygen, thereby defining a first reaction zone, which has an extension Δx_1, in the longitudinal direction, and in that the gasification reactor further has a downstream second inlet for supplying the gasification agent thereby defining a second reaction zone. The second reaction zone has an extension Δx_2 in the longitudinal direction and is arranged at a distance from the first inlet, which is preferably defined as $x_1 \leq \frac{\Delta x_1 + \Delta x_2}{2}$, such that the first reaction zone at least partly overlaps the second reaction zone. In the first and/or second reaction zone all sub-processes of the gasification process may occur.

[0035] The gasification reactor according to the second aspect of the invention may be used in a gasifier according to the first aspect of the invention. Preferred embodiments and benefits according to the first aspect of the invention are therefore also preferred embodiments and benefits of the gasification reactor according to the second aspect and vice versa.

[0036] In a third aspect, the invention relates to a power generation system, comprising a functional unit configured to provide a thermal and/or an electric energy by combustion of a product gas, and a gasifier according to the first aspect of the invention, which is in fluid communication with the functional unit. The gasification reactor or a number of gasification reactors may be configured to provide the product gas for operating the functional unit. In alternative the gasification reactor may be configured to provide the product gas for operating a number of functional units. The power generation system according to the third aspect of the invention having a gasifier according to the first aspect of the invention makes use of the benefits described above with respect to the first aspect of the invention. Therefore, preferred embodiments and benefits according to the first aspect of the invention are therefore also preferred embodiments and benefits of the power generation system according to the third aspect and vice versa.

[0037] In a preferred embodiment, the functional unit comprises an electric generator for conversion of kinetic energy into electrical energy and a combustion engine configured to advance the supply kinetic energy to the generator, wherein the gasifier is configured to provide the product gas for operating the combustion engine.

[0038]   In a fourth aspect, the invention relates to a method for operating a gasifier, in particular a gasifier according to the first aspect of the invention, comprising the steps:

- feeding a feedstock material from a container through a gasification reactor in a longitudinal direction,
- supplying a gasification agent comprising oxygen to the gasification reactor via a first inlet to define a first reaction zone to provide a heat amount in said first reaction zone, the first reaction zone having an extension Δx_1, in the longitudinal direction,
- supplying a gasification agent comprising oxygen to the gasification reactor via a second inlet to define a second reaction zone to provide a heat amount in said first reaction zone, the second reaction zone having an extension Δx_2 in the longitudinal direction,

  wherein the second inlet is arranged at a distance from the first inlet, which is preferably defined as $x_1 \leq \frac{\Delta x_1 + \Delta x_2}{2}$, such that the first reaction zone at least partly overlaps the second reaction zone,
- partial oxidizing the feedstock material under supply of the gasification agent in the first and second reaction zone,
- pyrolysis the feedstock material in said reaction zone to provide a pyrolysis product in the first and second reaction zone, and
- gasifying the pyrolysis product into a product gas at least in the second reaction zone.

[0039]   The method for operating a gasifier makes use of the benefits described above with respect to the gasifier according to the first aspect by defining a first and a second reaction zone due to the introduction of the gasification agent. Therefore, preferred embodiments and benefits according to the first aspect of the invention are therefore also preferred embodiments and benefits of the power generation system according to the fourth aspect and vice versa.

[0040]   Having a number i of inlets each having an each extension Δx_i, the temperature varies along each extension Δx_i of the respective reaction zone. It is preferred, that the distances x_i of the inlets is chosen such that the temperature first increases in the direction of the material flow, which is the longitudinal direction, and remains above a minimum temperature T_{Min} that is defined by the formula $T_{Min} \geq \frac{T_{i-1} + T_i}{2}$, preferably by $T_{Min} \geq 4 \cdot \frac{T_{i-1} + T_i}{5}$.

[0041]   It will be understood, that upstream the first inlet and downstream the last downstream inlet, the temperature may fall below said minimum temperature, since there is no overlapping area of the reaction zones provided.

[0042]   For a more complete understanding of the invention, the invention will now be described in detail with reference to the accompanying drawings. The detailed description will illustrate and describe what is considered as a preferred embodiment of the invention. In the accompanying drawings:

Fig. 1   shows a gasification reactor according to the prior art in a schematic view;

Fig. 2   shows a gasification reactor according to a first preferred embodiment in a schematic view;

Fig. 3   shows a gasification reactor according to a second preferred embodiment in a schematic view;

Fig. 4   shows a gasifier according to a first preferred embodiment;

Fig. 5   shows a gasifier according to a second preferred embodiment in a schematic view;

Fig. 6   shows a gasifier according to a third preferred embodiment in a schematic view;

Fig. 7   shows a power generation system according to a first preferred embodiment in a schematic view;

Fig. 8   shows a power generation system according to a second preferred embodiment in a schematic view; and

Fig. 9   shows a power generation system according to a third preferred embodiment in a schematic view.

[0043]   Fig. 1 shows a gasification reactor 1 according to the prior art. The gasification reactor 1 comprises a pipe 3 defining a flow path for a feedstock material.

[0044]   The gasification reactor 1 further has an inlet, which is defined as a set of inlets 7, 8 arranged in the pipe 3 and distributed in the circumferential direction. By way of example, only two inlets 7, 8 of the set of inlets are indicated by reference signs. It will be understood, that any number of inlets may form the set of inlets.

[0045] The set of inlets 7, 8 are configured for supplying a gasification agent comprising oxygen. Such a gasification agent may for example be ambient air. By supplying the gasification agent, the first inlet 7 and the second inlet 8 define a first reaction zone 5, which has an extension Δx in the longitudinal direction L. The reaction zone 5 starts at a position upstream the set of inlets 7, 8 and extends downstream the set of inlets 7, 8. If the temperature in the reaction zone 5 is sufficiently high a product gas is produced from feedstock material.

[0046] During operation of the gasification reactor 1, the feedstock material moves through the pipe 3, wherein the gasification agent supplied by the set of inlets 7, 8 increases the temperature of the feedstock material, such that volatiles, in particular tar droplets, are dissipated from the feedstock material. Carbon atoms from the tar droplets as well as the remaining carbon skeleton undergo an oxidation process with the oxygen contained in the gasification agent thereby producing CO_2. The oxidation process can also be described as a combustion process, since high temperatures are achieved allowing the further sub-processes of the gasification process to convert the remaining pyrolysis and oxidation products into a product gas.

[0047] As shown in Fig. 1, the temperature T in the reaction zone 5 is not uniform and instead increases to a maximum T_{Max} proximate downstream the set of inlets 7, 8 and decreases afterwards. In a certain area, the temperature reaches a maximum for the gasification reactions. Upstream and downstream from the reaction zone 5, the feedstock material cannot be converted into a product gas, since the required temperatures are not reached within the gasification reactor 1.

[0048] By increasing the flow of the gasification agent, the temperature might increase and to some extend also the size of the reaction zone 5, however, the temperature cannot exceed a certain limit without either damaging the walls of the gasifier 10, or requiring expensive technical measures, like ceramic insulations.

[0049] Provided that the gasification reactor 1 converts the feedstock material completely into a product gas within the reaction zone 5, the feedstock material moves at a velocity sufficiently low such that the feedstock material may be converted along the extension Δx under the given flow of gasification agent.

[0050] In order to increase the material throughput and therefore the power of the gasifier, the amount of gasification agent supplied to the gasification reactor 1 may be increased. However, the conversion of the feedstock material is limited by the length Δx of the reaction zone 5. Thus, increasing the power will require to increase the temperature within the gasification reactor 1 that may result in damage of the pipe 3.

[0051] Fig. 2 depicts a gasification reactor 1 according to a first preferred embodiment of the present invention.

[0052] The gasification reactor 1 extends in a longitudinal direction L and may comprise a pipe 3. Instead of a pipe, any other suitable form can be chosen which allows the transportation of a feedstock material through the gasification reactor 1. The gasification reactor 1 has a number of inlets i=2.

[0053] The gasification reactor 1 has a first set of inlets 7.1, 8.1 arranged opposite to each other, which define a first inlet for supplying a gasification agent comprising oxygen to the gasification reactor 1. By way of example, only two inlets 7.1, 8.1 included in the set of inlets are indicated by reference signs. It will be understood, that any number of inlets may form the set of inlets. The number of inlets may be uniform distributed in the circumferential direction providing a more uniform supply of the gasification agent at a predefined position in the longitudinal direction L. By supplying the gasification agent to the gasification reactor 1, the first set of inlets 7.1, 8.1 define a first reaction zone 5.1. The first reaction zone 5.1 has an extension Δx_1, in the longitudinal direction L.

[0054] The gasification reactor 1 further has a second inlet defied by a second set of inlets 7.2, 8.2 arranged opposite to each other. The second set of inlets 7.2, 8.2 is arranged downstream the first set of inlets 7.1, 8.1 at a distance x_1 in the longitudinal direction L. By way of example, only two inlets 7.2, 8.2 of included in the set of inlets are indicated by reference signs. It will be understood, that any number of inlets may form the set of inlets. The number of inlets may be uniform distributed in the circumferential direction providing a more uniform supply of the gasification agent at a predefined position in the longitudinal direction L. By supplying the gasification agent to the gasification reactor 1, the second set of inlets 7.2, 8.2 define a second reaction zone 5.2. The second reaction zone 5.2 has an extension Δx_2 in the longitudinal direction L.

[0055] Fig. 2 thereby illustrates the size and the temperature of this reaction zone 5.1 as it would be in the absence of the downstream inlets 7.2, 8.2. In addition, zone 5.2 is shown, as it would be in absence of the upstream inlets 7.1, 8.1.

[0056] As shown in the schematic view in Fig. 2, the distance x_1 is smaller than the extension Δx_1, of the first reaction zone and the extension Δx_2 of the second reaction zone. As such, an overlapping area 9.1 in which the first reaction zone 5.1 overlaps the second reaction zone 5.2 is provided.

[0057] The reaction zones 5.1 and 5.2 as shown in Fig. 2 are illustrated, as they would result in the absence of any neighboring inlets. If instead the gasification agent is supplied to all inlets, the temperatures profiles of reaction zones 5.1 and 5.2 will in first approximation add to a common reaction zone. As a result, the maximum temperature T_{Max} is not reached in only the maxima of 5.1 and 5.2, but rather over the whole length of x_1. Therefore, the volume within the gasification reactor 1 in which high-temperature reactions can occur, strongly increases.

[0058] As described above, the velocity of the feedstock material through the gasification reactor 1 is limited by the time needed to convert the whole feedstock material arranged along a predefined extension (not shown) within the respective reaction zone.

[0059] By having a first reaction zone 5.1 and a second reaction zone 5.2, the velocity of the feedstock material through the gasification reactor 1 can be increased and thus resulting in an increased power of the gasification reactor 1. As such, twice of the amount of feedstock material can be converted into a product gas within the same time due to the first reaction zone 5.1 and the second reaction zone 5.2. Since the amount of gasification agent supplied to each one of the reaction zones 5.1, 5.2 remains constant when compared to the gasification reactor 1 shown in Fig. 1, the temperature will not be increased and thus damage of the pipe 3 can be avoided.

[0060] The embodiment of the gasification reactor 1 shown in Fig. 3 differs from the embodiment shown in Fig. 2 by the number i=4 of inlets, each defined by a set of inlets for supplying a gasification agent.

[0061] In Fig. 3, the gasification reactor 1 has a first set of inlets 7.1, 8.1 defining a first reaction zone 5.1. The gasification reactor 1 further has a second set of inlets 7.2, 8.2 defining a second reaction zone 5.2, a third set of inlets 7.3, 8.3 defining a third reaction zone 5.3 and a fourth set of inlets 7.4, 8.4 defining a fourth reaction zone 5.4.

[0062] Each one of the sets of inlets 7.1, 8.1, 7.2, 8.2, 7.3, 8.3, 7.4, 8.4 is configured to supply a gasification agent comprising oxygen to the gasification reactor 1. By way of example, only two inlets of each set of inlets are indicated by reference signs. It will be understood, that any number of inlets may form the respective set of inlets. The number of inlets may be uniform distributed in the circumferential direction providing a more uniform supply of the gasification agent.

[0063] The first set of inlets 7.1, 8.1 is arranged at a distance from the downstream second set of inlets 7.2, 8.2. The second set of inlets 7.2, 8.2 is arranged at a distance x_2 from the downstream third set of inlets 7.3, 8.3. The third set of inlets 7.3, 8.3 is arranged at a distance x_3 from the downstream fourth set of inlets 7.4, 8.4. In Fig. 3, only the distances x_2, x_3 are indicated by reference signs by way of example. As shown in the schematic view in Fig. 3, the distance x_3 is smaller than the average of the extension Δx_3 of the third reaction zone 5.3 and the extension Δx_4 of the fourth reaction 5.4 zone. As such, an overlapping area 9.3 in which the third reaction zone 5.3 overlaps the fourth reaction zone 5.4 is provided.

[0064] It will be understood that the inlets can either be uniform distributed over having a varying distance from each other.

[0065] The first reaction zone 5.1 and the second reaction zone 5.2 overlap each other in an overlapping area 9.1. The third reaction zone 5.3 and the second reaction zone 5.2 overlap each other in an overlapping area 9.2. The fourth reaction zone 5.4 and the third reaction zone 5.3 overlap each other in a third overlapping area 9.3, since the distance between each set of inlets 7.1 - 8.4 and the respective upstream set of inlets is smaller than the associated reaction zone 5.1 - 5.4.

[0066] Thus, the extension in the longitudinal direction L in which the temperature can be held close to the temperature T_{Max} is further increased, and also the power is increased with respect to the situation and in particular the temperature profile described with respect to Fig. 2. In consequence, additional inlets may be added, to further increase the length of the high temperature zone and to further increase the power of the gasifier 10. A very compact gasifier 10 with a very high power results, delivering a product gas of high quality.

[0067] Fig. 4 shows the gasifier 10 according to a first preferred embodiment. The gasifier 10 comprises the gasification reactor 1, a container 11 configured to receive feedstock material. The container 11 is arranged upstream the gasification reactor 1.

[0068] The gasifier 10 preferably further comprises a feeding unit 13, which is at least partly arranged in the gasification reactor 1, in particular in a pipe 3 of the gasification reactor 1. The feeding unit 13 may be provided by a snake conveyor, which is configured for feeding the feedstock material from the container 11 through the pipe 3 of the gasification reactor 1.

[0069] The gasification reactor 1 has a number of reaction zones 5.1, 5.2, 5.i defined by a number of inlets *i* each defined by a set of inlets 7.1, 8.1, 7.2, 8.2, 7.i, 8.i which are configured for supplying a gasification agent to the gasification reactor 1.

[0070] The feeding unit 13 is preferably arranged upstream the number of reaction zones 5.1, 5.2, 5.i.

[0071] By way of example, only the reaction zones 5.1, 5.2, 5.i are indicated by reference signs. It will be understood, that the number of reaction zones is not limited to the number shown in the embodiment.

[0072] By way of example, only the sets of inlets 7.1, 8.1, 7.2, 8.2, 7.i, 8.i are indicated by reference signs. It will be understood, that the number of sets of inlets is not limited to the number shown in the embodiment.

[0073] Fig. 5 shows the gasifier 10 according to a second preferred embodiment.

[0074] The embodiment shown in Fig. 5 differs from the embodiment shown in Fig. 4 by the form of the gasification reactor 1.

[0075] The gasification reactor 1 in Fig. 5 has a frustoconical end portion 14 arranged in an area downstream the feeding unit 13 such that the cross section of the gasification reactor 1 increases with the distance from the feeding unit 13 in the longitudinal direction L.

[0076] In the embodiments shown in Figs. 4 and 5, the feedstock material is transported from a lower end of the gasification reactor 1 to its upper end. In this case, the frustoconical end portion 14 allows the supply of the gasification agent with an increased velocity, since the weight force provided by the feedstock material within the end portion 14 avoids the acceleration of the product gas and/or oxygen to an extent which results in an undesired moving away of the

remaining feedstock material.

[0077] Fig. 6 shows the gasifier 10 according to a third preferred embodiment.

[0078] The gasifier 10 shown in Fig. 6 differs from the gasifier shown in Fig. 4, on the one hand, by a shell 15 that encloses the sets inlets 7.1, 7.2 - 7.i, 8.i defining a number of reaction zones 5.1 - 5.i.

[0079] The shell 15 provides a gasification agent supplied by a supply 17 access to the each one of the sets of inlets 7.1, 7.2 - 7.i, 8.i.

[0080] Preferably, the shell 15 is coaxially arranged to the gasification reactor 1 at a distance in the radial direction, such that the gasification agent can be well distributed before entering the sets of inlets 7.1, 7.2 - 7.i, 8.i.

[0081] Further preferred, the gasifier 1 hat control unit 19 being in signal communication with the supply 17. Preferably, the control unit 19 is configured to control the amount of the gasification agent supplied by the supply 17 to the number of inlets 7.1, 7.2 - 7.i, 8.i.

[0082] The gasifier may further has a detection unit 21, which is in signal communication with the control unit 19. The control unit 19 may selectively control the supply 17 for supplying an amount of the gasification agent to a respective one of the number of fluid inlets 7.1, 7.2 - 7.i, 8.i based on a signal provided by the detection unit 21. The detection unit 21 is preferably arranged within the shell 15.

[0083] The detection unit 21 may comprise a temperature sensor or a pressure sensor for detecting the temperatures within a respective one of the reaction zones 5.1 - 5.i or the pressures at a respective one of the inlets 7.1, 7.2 - 7.i, 8.i.

[0084] Depending on the sensed pressure and/or temperature, the control unit 19 may selectively increase the amount of gasification agent supplied by the supply 17 to a predefined one of the fluid inlets 7.1, 7.2 - 7.i, 8.i to increase the temperature and/or pressure.

[0085] Fig. 7 depicts a power generation system 100 according to a first preferred embodiment. The power generation system 100 may comprise a functional unit 23 configured to provide a thermal and/or an electric energy by the combustion of a product gas.

[0086] The power generation system 100 further comprises a gasifier 10 according to a preferred embodiment of the invention.

[0087] The gasifier 10 comprises a container 11, a gasification reactor 1 arranged downstream the container 11, and a feeding unit 13 configured for feeding a feedstock material from the container 11 through the gasification reactor 1. The power generation system 100 further comprises a conduit 25 for supplying the product gas from the gasifier 10 to the functional unit 23.

[0088] The gasifier 10 is configured for converting the feedstock material received in the container 11 into a product gas in the at least two reaction zones as described with regard to Figs. 2 and 3.

[0089] The functional unit 23 may be a thermal power plant, a chemistry plant configured for converting the product gas into a fuel, or a vehicle, which is advanced by combustion of the product gas.

[0090] Fig. 8 shows a second preferred embodiment of the power generation system 100. In the embodiment shown in Fig. 8, the functional element is a combustor 27 configured to combust the product gas provided by the gasifier 10 in order to provide thermal energy. Said thermal energy may be provided to a district heating pipeline used for heating any kinds of buildings or plants.

[0091] Fig. 9 shows a power generation system 100 according to a third preferred embodiment. The power generation system 100 comprises a gasifier 10 as described with respect to Figs. 4 to 6. The functional unit in this embodiment is provided by a combustion engine 31 and an electric generator 29. The electric generator 29 is configured to convert kinetic energy into electric energy.

[0092] In the power generation system 100, the gasifier 10 converts a biomass feedstock material, which is received in the container 11 into a product gas by a gasification process. The product gas is used to operate a combustion engine 31, as, for example, a combustion motor. The combustion engine 31 is configured to provide kinetic energy by combusting a fuel as, for example, the product gas. The generator 29 then converts the kinetic energy provided by the combustion engine 31 into electric energy in a known manner.

[0093] The amount of product gas provided to the combustion engine 31 or to the functional unit 23 shown in Fig. 7 orto the combustor 27 shown in Fig. 8 depends on the amount of feeding material that can be converted into product gas in a predefined time frame. Thus, the power of the power generation system 100 depends on the velocity in which the feedstock material can move through the gasification reactor 1 allowing a total conversion of the feedstock material. The conversion rate depends on the temperature, which is limited by possible damage of the gasification reactor 1 as described above.

[0094] Thus, by providing a number of subsequent reaction zones as described with respect to Figs. 2 and 3, the power of the power generation system is increased.

[0095] The gasifiers shown in Figs. 4 to 6 may be operated by a method comprising the feeding of a feedstock material from the container 11 through the gasification reactor 1 in the longitudinal direction L. The method further comprises supplying a gasification agent to the first reaction zone 5.1 and the second reaction zone 5.2 via the corresponding first set of inlets and via the second set of inlets 7.2, 8.2. Further, the gasification agent may be supplied to a number of

downstream-arranged subsequent reaction zones via their corresponding inlets. The method further includes partially oxidizing the feedstock material under supply of the gasification agent in at least one of the reaction zones to provide a heat amount for the subsequent pyrolysis of the feedstock material in said reaction zones to provide a pyrolysis product. Further, the method includes finally gasifying the pyrolysis product, preferably in the absence of oxygen, into a product gas. Since the amount of feedstock material will decrease in the downstream direction and the amount converted into pyrolysis products and product gas and the amount consumed in oxidation will increase, at some point combustion and reduction reactions may increase compared to the pyrolysis reactions mainly occurring in the reaction zones subsequent the feeding unit 13.

List of reference signs

[0096]

1	gasification reactor
3	pipe
5, 5.1, 5.2, 5.3, 5.4, 5.i	reaction zone
7, 7.1, 7.2, 7.3, 7.4, 7.i	first inlet (7.1, 8.1)
8, 8.1, 8.2, 8.3, 8.4, 8.i	second inlet (7.2, 8.2)
9.1, 9.2, 9.3	overlapping area
10	gasifier
11	container
13	feeding unit
14	frustoconical end portion
15	shell
17	supply
19	control unit
21	detection unit
23	functional unit
25	conduits
27	combustor
29	electric generator
31	combustion engine
100	power generation system
L	longitudinal direction
$\Delta x_1, \Delta x_2, \Delta x_3, \Delta x_3$	extension
x_1, x_2, x_3	distance

Claims

1. Gasifier (1) for converting carbonaceous feedstock material into a product gas, comprising:

   - a container (11) configured to receive a feedstock material,
   - a gasification reactor (10) extending in a longitudinal direction (L) and arranged downstream the container (11),
   - a feeding unit (13) for feeding the feedstock material from the container (11) through the gasification reactor (10) in the longitudinal direction (L),

      wherein the gasification reactor (10) has a first inlet (7.1, 8.1) for supplying a gasification agent comprising oxygen thereby defining a first reaction zone (5.1) , the first reaction zone (5.1) having an extension (Δx_1) in the longitudinal direction (L),
      wherein the gasification reactor (10) further has a downstream second inlet (7.2, 8.2) for supplying the gasification agent thereby defining a second reaction zone, the second reaction zone (5.2) having an extension (Δx_2) in the longitudinal direction (L),
      wherein the second inlet (7.2, 8.2) is arranged at a distance (x_1) from the first inlet (7.1, 8.1), which is defined as

$$x_1 \leq \frac{\Delta x_1 + \Delta x_2}{2}$$, such that the first reaction zone (5.1) at least partly overlaps the second reaction zone (5.2).

2. Gasifier (1) according to claim 1,
   wherein the gasification reactor (10) is configured for partial oxidation of the feedstock material in the reaction zone (5.1, 5.2, 5.3, 5.4, 5.i) under supply of the gasification agent to provide a heat amount and for pyrolysis of the feedstock material under supply of said heat amount.

3. Gasifier (1) according to claim 1 or 2,

   wherein the gasification reactor (10) further has a number of inlets (7.3, 8.3, 7.4, 8.4, 7.i, 8.i) downstream the first inlet (7.1, 8.1) and the second inlet (7.2, 8.2), for supplying gasification agent thereby defining a number of reaction zones (5.3, 5.4, 5.i) each having an extension (Δx_3, $\Delta x_{4,}$) in the longitudinal direction (L),
   wherein each inlet (7.3, 8.3, 7.4, 8.4, 7.i, 8.i) is arranged at a distance (x_3, x_4) in the longitudinal direction (L) from the respective upstream adjacent inlet, which is preferably defined as

   $$x_i \leq \frac{\Delta x_{i-1} + \Delta x_i}{2}$$, such each reaction zone (5.2, 5.3, 5.4, 5.i) at least partly overlaps the upstream adjacent reaction zone (5.1, 5.2, 5.3, 5.4).

4. Gasifier (1) according to claim 3,
   wherein the inlets (7.3, 8.3, 7.4, 8.4, 7.i, 8.i) are uniform distributed in the in the longitudinal direction (L) having an equal distance (x_1, x_2, x_3) from the respective upstream adjacent one of the inlets (7.3, 8.3, 7.4, 8.4, 7.i, 8.i).

5. Gasifier (1) according to any one of the preceding claims,
   wherein the gasification reactor (10) is configured for pyrolysis of the feedstock material in the reaction zone (5.1, 5.2, 5.3, 5.4, 5.i) at a temperature between 300°C and 600°C to form a pyrolysis product and for gasifying the pyrolysis product in the reaction zone (5.1, 5.2, 5.3, 5.4, 5.i) at a temperature between 700°C and 1500°C to form a product gas.

6. Gasifier (1) according to any one of the preceding claims,
   wherein the container (11) and/or the gasification reactor (10) is configured for heating the feedstock material up to an evaporation temperature above 100°C to evaporate water contained in the feedstock material.

7. Gasifier (1) according to any one of the preceding claims,
   wherein the gasification reactor (10) has a conical end portion (14), in particular arranged in an area downstream the feeding unit (13).

8. Gasifier (1) according to any one of the preceding claims,
   wherein at least one inlet is provided by a set of inlets (7.1, 8.1-7.i, 8.i), wherein the set of inlets comprises a number of inlets, which are arranged at a predefined position along the longitudinal axis (L) and distributed in a circumferential direction.

9. Gasifier (1) according to any one of the preceding claims,
   wherein at least the first upstream arranged inlet (7.1, 8.1) has the form of a slit, and the slit preferably extends perpendicular to the longitudinal direction (L).

10. Gasifier (1) according to any one of the preceding claims,
    wherein the gasification reactor (10) has a supply (17) for the gasification agent, and the gasifier (1) further has a control unit (19) being in signal communication with the supply (17) for controlling the amount of gasification agent provided by the supply (17) at least to the first inlet (7.1, 8.1).

11. Gasifier (1) according to claim 10,
    wherein the gasification reactor (10) has at least one detection unit (21) configured to detect a temperature and/or a pressure at least at one of the inlets (7.1, 8.1-7.i, 8.i) and/or in at least one of the reaction zones (5.1, 5.2, 5.3, 5.4, 5.i).

12. Gasifier (1) according to claim 10 or 11,

wherein the gasification reactor (10) has a shell (15) enclosing the at least one inlet (7.1, 8.1-7.i, 8.i), which is in fluid communication with the supply (17) for the gasification agent.

13. Gasifier (1) according to any one of the preceding claims,
   wherein the gasification reactor (10) has a cleaning mechanism for automatically cleaning at least one inlet (7.1, 8.1-7.i, 8.i), preferably the first inlet (7.1, 8.1) arranged subsequent the container (11), without interrupting gasifier (1)

14. Gasification reactor (10) for gasification of a feedstock material in a gasifier, in particular in a gasifier (1) according to any one of the claims 1 to 13,

   wherein the gasification reactor (10) extends in a longitudinal direction (L) and is configured to be arranged downstream a container (11) of the gasifier and to cooperate with a feeding unit (13) for feeding the feedstock material from the container (11) through the gasification reactor (10) in the longitudinal direction (L),
   wherein the gasification reactor (10) has a first inlet (7.1, 8.1) for supplying a gasification agent comprising oxygen thereby defining a first reaction zone (5.1), the first reaction zone (5.1) having an extension (Δx_1) in the longitudinal direction (L),
   wherein the gasification reactor (10) further has a downstream second inlet (7.2, 8.2) for supplying the gasification agent thereby defining a second reaction (5.2) zone, the second reaction zone (5.2) having an extension (Δx_2) in the longitudinal direction (L),
   wherein the second inlet (7.2, 8.2) is arranged at a distance (x_1) from the first inlet (7.1, 8.1), which is preferably defined as

   $$x_1 \leq \frac{\Delta x_1 + \Delta x_2}{2}$$, such that the first reaction zone (5.1) at least partly overlaps the second reaction zone (5.2).

15. Power generation system (100), comprising:

   - a functional unit (23) configured to provide a thermal and/or an electric energy by combustion of a product gas, and
   - a gasifier (1) according to any one of the claims 1 to 13 being in fluid communication with the functional unit (23) and configured to provide the product gas for operating the functional unit (23).

16. Power generation system (100) according to claim 15,

   wherein the functional unit (23) comprises an electric generator (29) for conversion of kinetic energy into electrical energy and a combustion engine (31) configured to advance the supply kinetic energy to the generator (29), and wherein the gasifier (1) is configured to provide the product gas for operating the combustion engine (31).

17. Method for operating a gasifier, in particular a gasifier (1) according to any one of the claims 1 to 13, comprising the steps:

   - feeding a feedstock material from a container (11) through a gasification reactor (10) in a longitudinal direction (L),
   - supplying a gasification agent comprising oxygen to the gasification reactor (10) to define a first reaction zone (5.1) to provide a heat amount in said first reaction zone (5.1) via a first inlet (7.1, 8.1), the first reaction zone (5.1) having an extension Δx_1 in the longitudinal direction (L),
   - supplying a gasification agent comprising oxygen to the gasification reactor (10) to define a second reaction zone (5.2) to provide a heat amount in said first reaction zone (5.1) via a second inlet (7.2, 8.2), the second reaction zone (5.2) having an extension (Δx_2) in the longitudinal direction (L),
   wherein the second inlet (7.2, 8.2) is arranged at a distance (x_1) from the first inlet (7.1, 8.1), which is defined as $x_1 \leq \frac{\Delta x_1 + \Delta x_2}{2}$, such that the first reaction zone (5.1) at least partly overlaps the second reaction zone (5.2),
   - partial oxidizing the feedstock material under supply of the gasification agent in the first and second reaction zone (5.1, 5.2),
   - pyrolysis the feedstock material in said first and second reaction zone (5.1, 5.2) to provide a pyrolysis product in the first and second reaction zone (5.1, 5.2), and
   - gasifying the pyrolysis product into a product gas at least in the second reaction zone (5.1, 5.2).
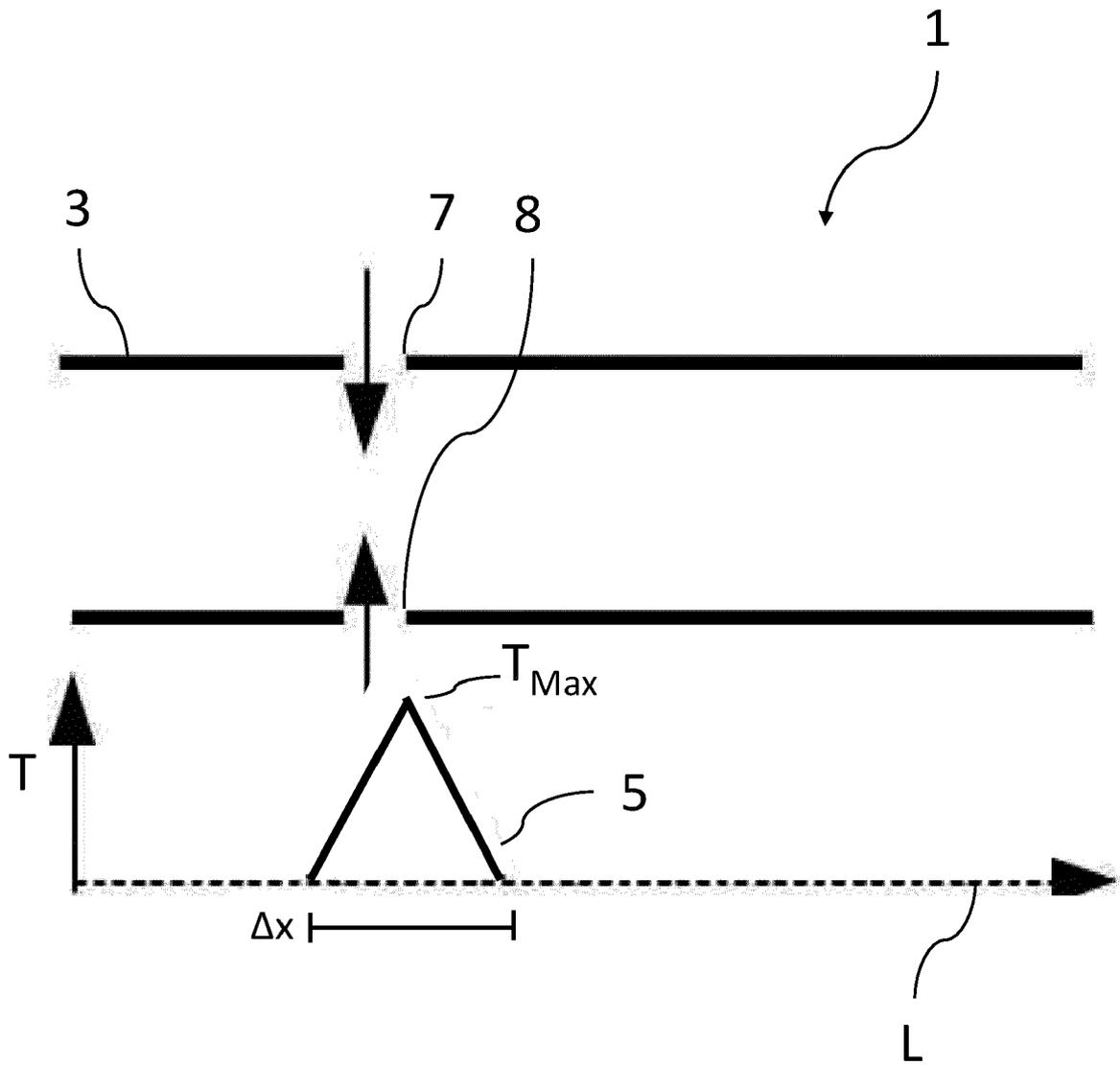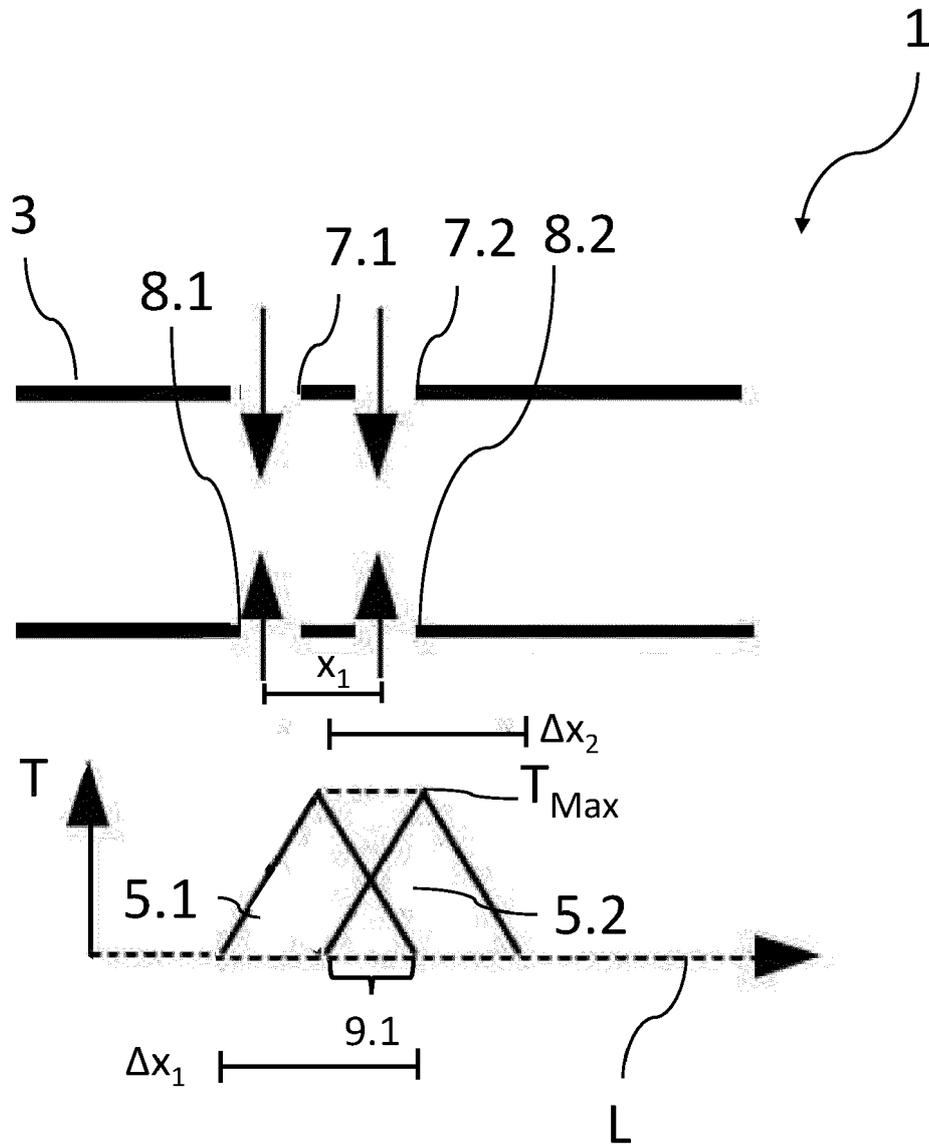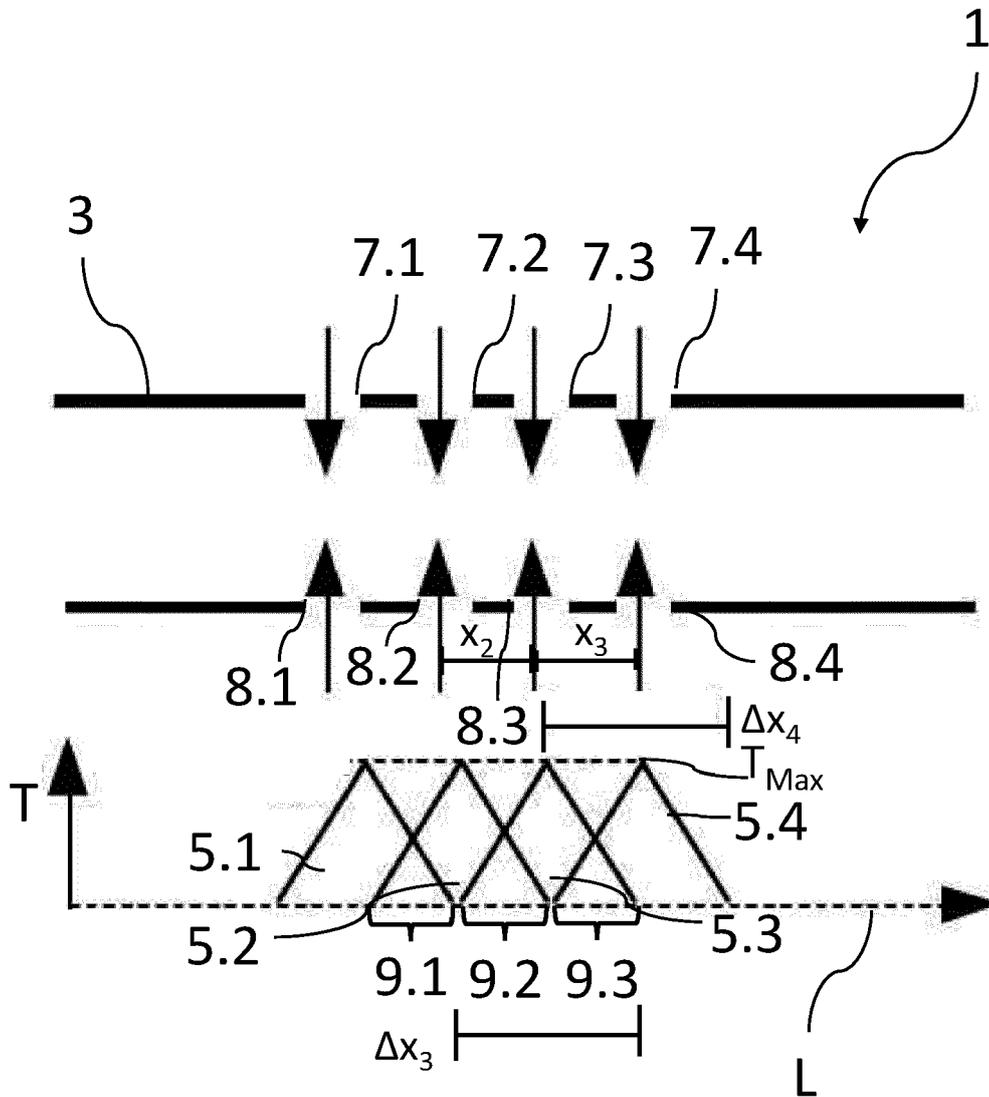
FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

100

23

25

11

1

10

13

FIG. 7

100

27

11

1

10

13

FIG. 8

29

100

31

G

M

11

1

10

13

FIG. 9

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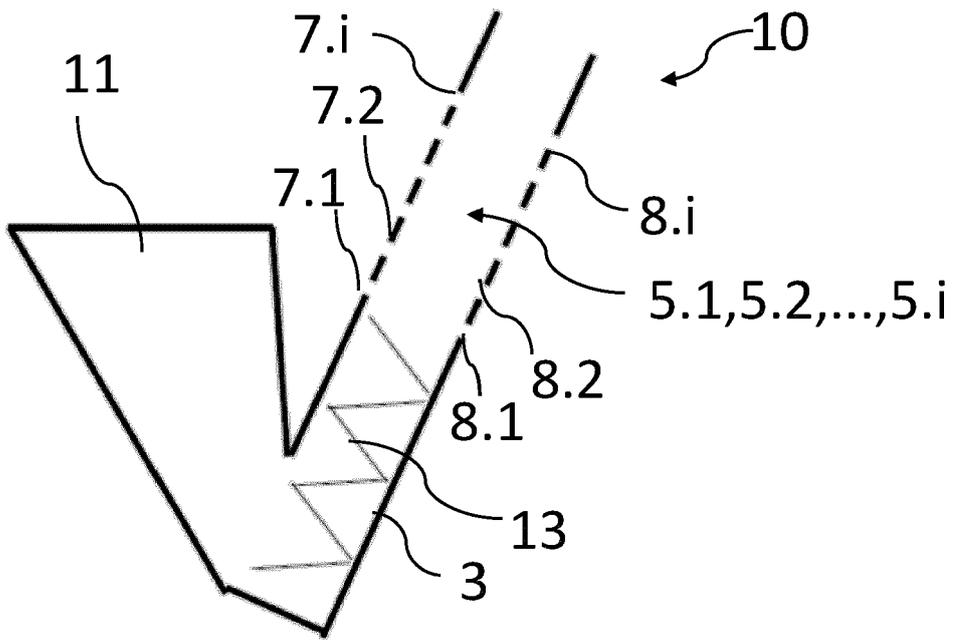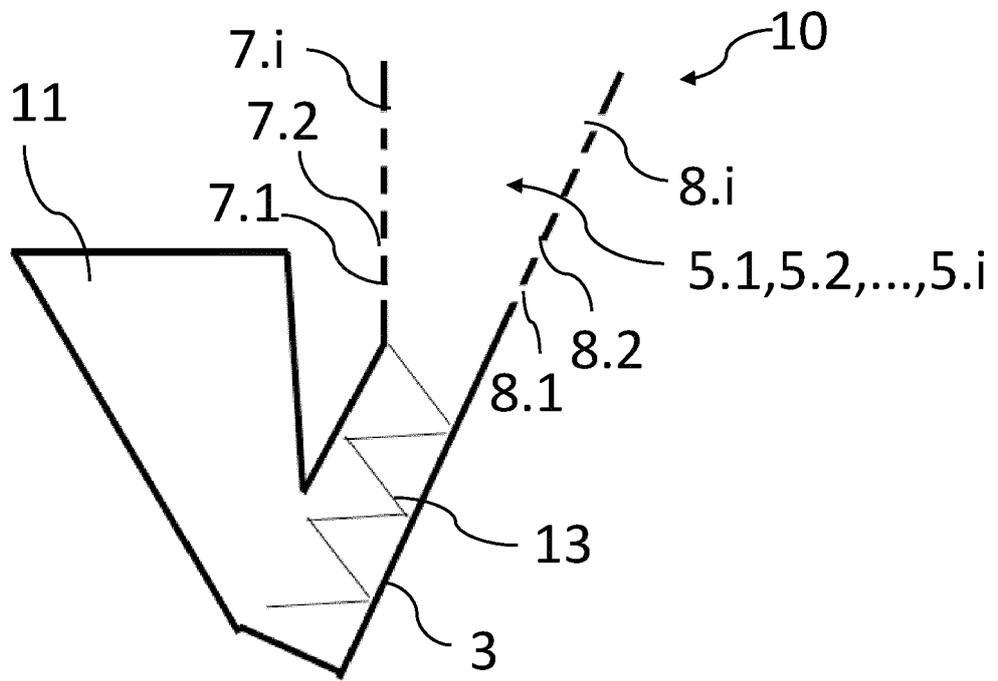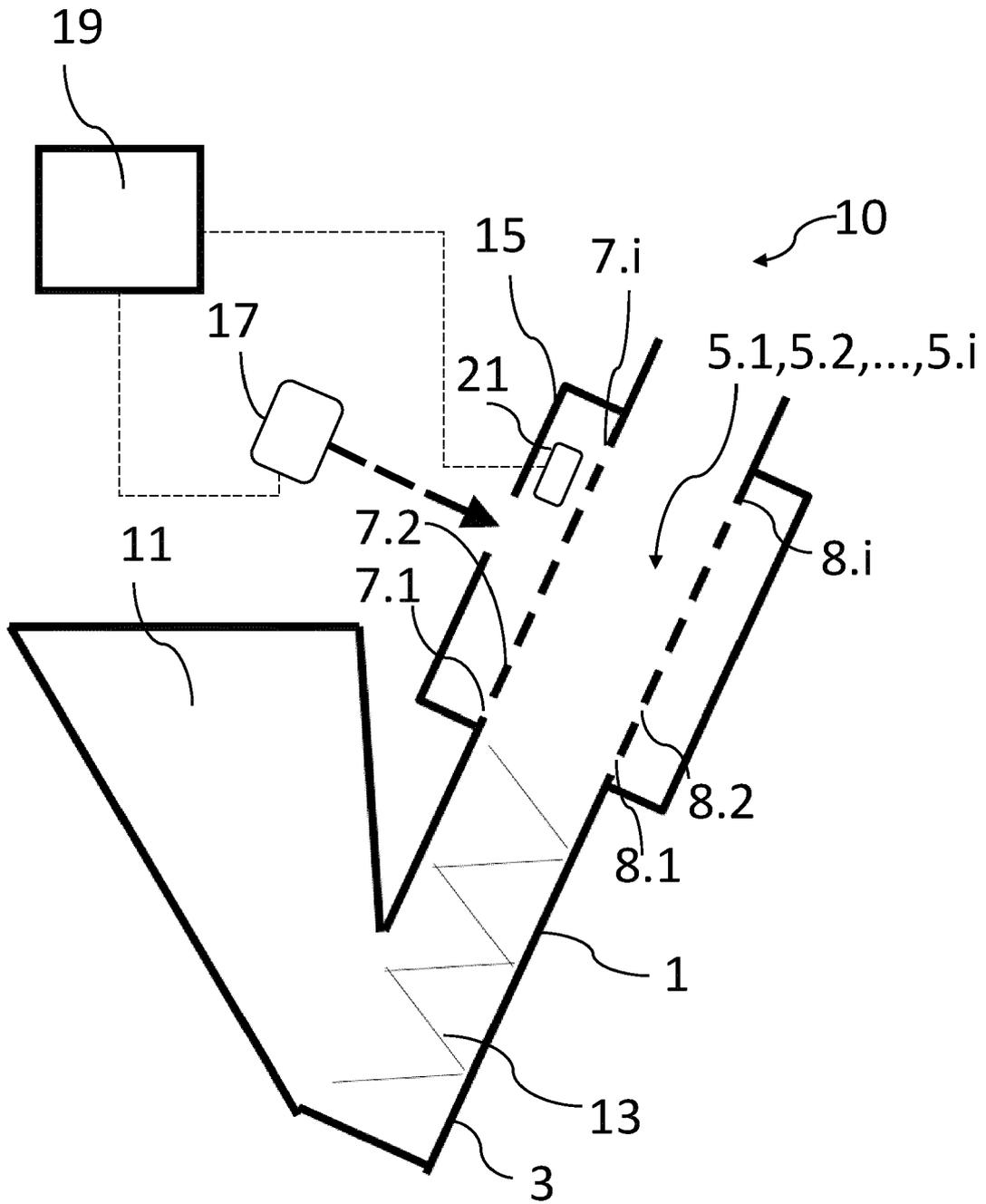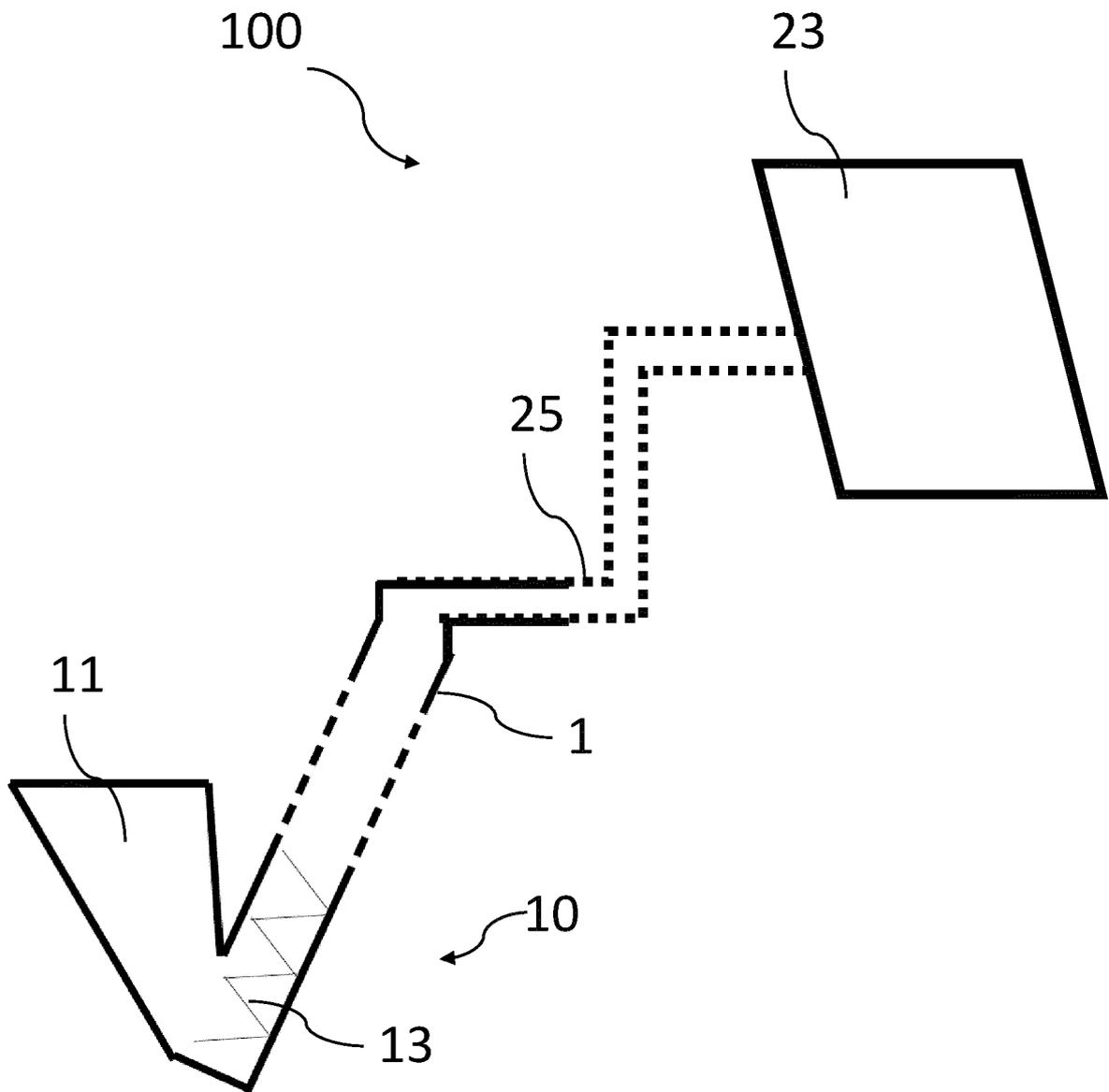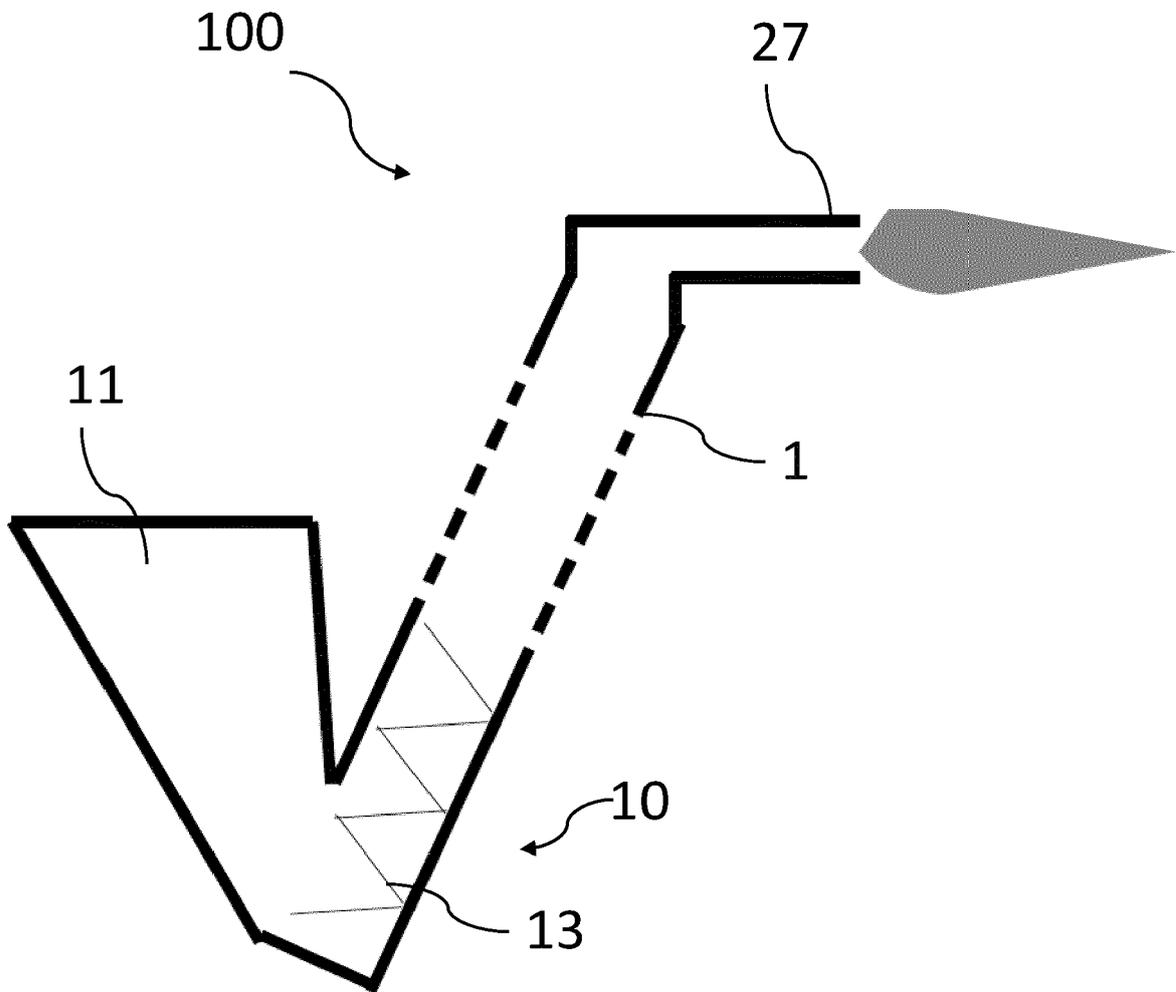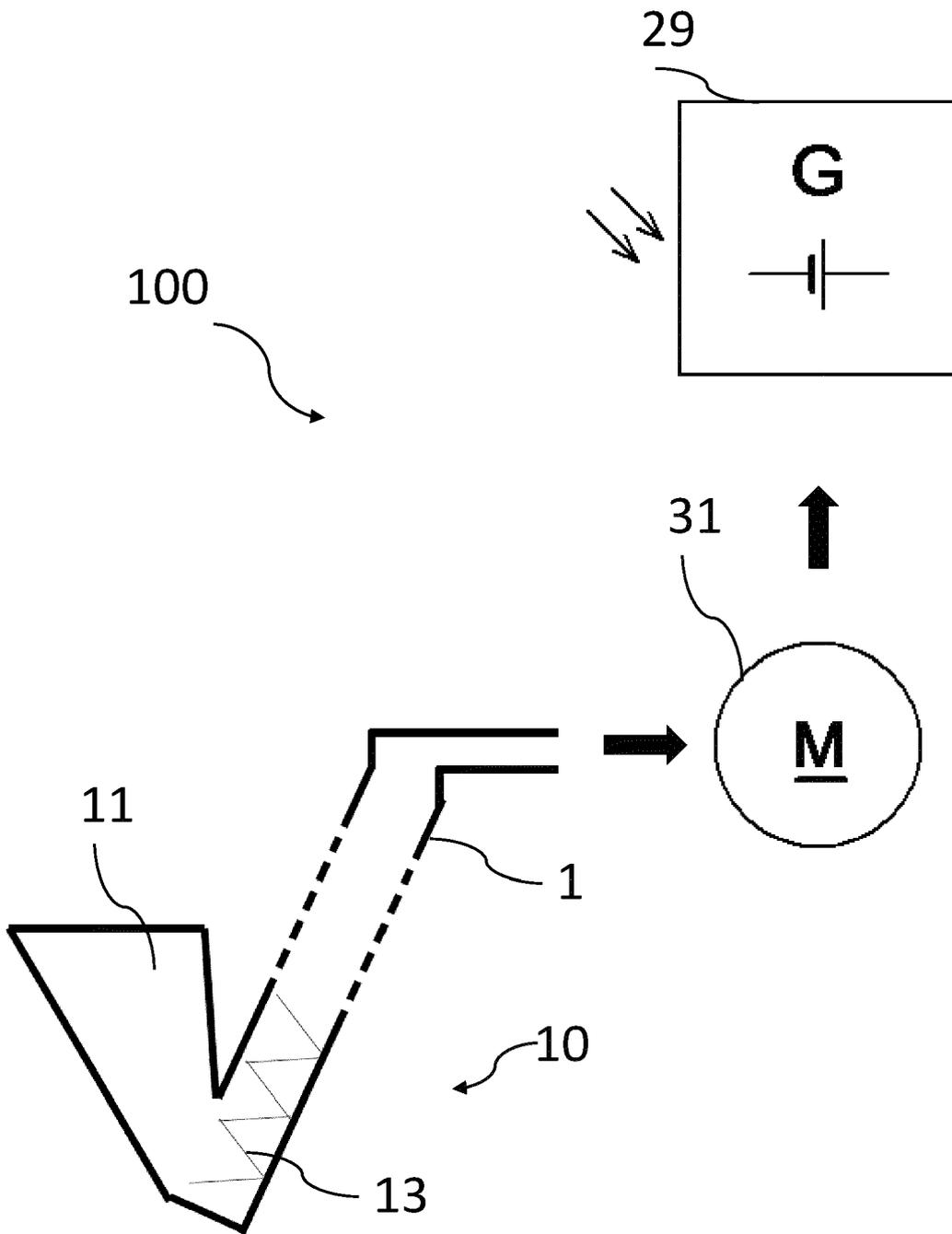
EUROPEAN SEARCH REPORT

Application Number

EP 22 19 3532

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	31 January 2023	Lachmann, Richard

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