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(54) **A CYCLONE GASIFIER**

(57) The present inventive concept relates to a cyclone gasifier comprising: a gasification chamber, a first and a second inlet, and a syngas exit pipe arranged at least partly inside the gasification chamber. The first inlet is arranged and configured to inject a first mixture of oxidant and particulate fuel into the gasification chamber such that a first swirling flow of the first mixture is established and allowed to propagate through at least a part of the gasification chamber. The second inlet is arranged and configured to inject a second mixture of oxidant and particulate fuel into the gasification chamber such that a second swirling flow of the second mixture is established and allowed to propagate through at least a part of the gasification chamber. The second swirling flow is at least partly offset in its propagation compared to the first swirling flow.

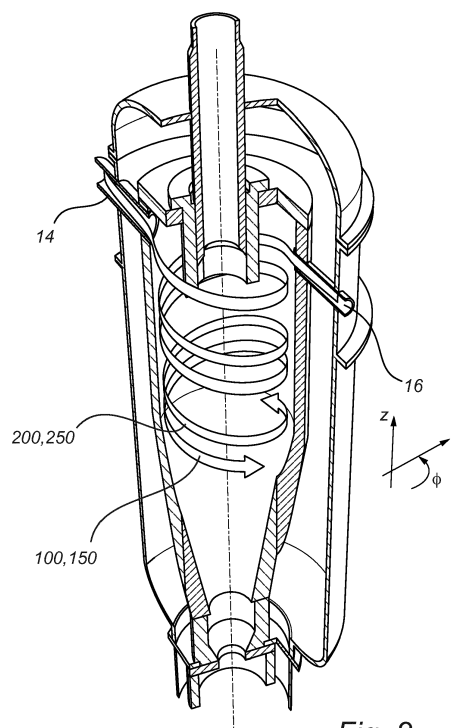


Fig. 2

Description

Technical field of the Invention

[0001] The present invention relates to a cyclone gasifier for gasifying a particulate fuel, to a system for producing a combustible gas having a cyclone gasifier, and to method for gasifying a particulate fuel with a cyclone gasifier.

Background of the Invention

[0002] Gasification of fuel, such as e.g. biomass, and subsequent combustion of the gas to generate power is an interesting small scale system for combined heat and power supply. Combustion of fuel to produce steam for use in a steam turbine is also used in large scale systems, e.g. having a power output of about 50 MW.

[0003] A cyclone, more commonly known for separation, may be used to produce combustible gas, e.g. syngas (synthesis gas), in a cyclone reactor or a cyclone gasifier. In such cyclone gasifier, a fuel is injected into the gasifier together with an oxidant whereby the syngas is produced together with residue ashes. The cyclone gasifier is advantageous to use as it allows for a combination of gasification and separation, i.e. gasification of the fuel and separation of the ashes. Furthermore, a cyclone gasifier is specifically suitable for use with pulverized fuel, whereby the combination of high effective area and high inlet velocities provides for a low residence time of the pulverized fuel.

[0004] In order for the reaction of the fuel and the oxidant to be initiated inside the gasifier, the cyclone gasifier is often pre-heated to the required temperature. This may e.g. be made by using an external energy source arranged inside the cyclone gasifier.

[0005] In one type of cyclone gasifiers, the gasification reactions occurs in a dense cloud of fuel particles that is blown into the cyclone gasifier where it forms a swirling flow, i.e. a vortex or a whirl, spinning down the reactor. The swirling flow is established by a combined effect of fuel injection parameters, cyclone gasifier design and the force of gravity. For example, the rate of which the fuel is injected into the gasifier (i.e. the velocity of the injection stream), the inner shape of the gasifier, the diameter of the inlet and the inner diameter of the gasifier are parameters affecting the swirling flow.

[0006] These types of cyclone gasifiers may be divided into at least two major parts, a first part located close to the inlet where the majority of the gasification process occurs, and a second part located distal to the inlet where residues, such as ashes are collected and subsequently removed from the cyclone gasifier. The produced syngas is preferably withdrawn from the gasifier through an exit pipe located in the first part of the gasifier.

[0007] In CN101781582, a cyclone gasifier having two fuel inlets is disclosed. Hereby, fuel from each of the two inlets may be gasified in the same cyclone gasifier.

[0008] However, there is a constant need in the industry to improve the efficiency of the cyclone gasifier.

Summary of the Invention

[0009] An object of the inventive concept is to overcome the above problems, and to provide for a cyclone gasifier which, at least to some extent more efficiently converts particulate fuel into syngas, compared to the prior art solutions. An object of the inventive concept is also to provide for cyclone gasifier which can be made smaller, i.e. more compact compared to the prior art solutions. This, and other objects, which will become apparent in the following, are accomplished by means of a cyclone gasifier, a system comprising a cyclone gasifier, and a method for gasifying a mixture of oxidant and particulate fuel by a cyclone gasifier, as defined in the accompanying claims.

[0010] The present inventive concept is based on the insight that by having two inlets, which each inject a mixture of oxidant and particulate fuel into the cyclone gasifier, two different swirling flows are allowed to propagate in the cyclone gasifier. Hereby, the space inside the cyclone gasifier may be better utilized as the two swirling flows are allowed to propagate through the cyclone gasifier differently and thus, the two swirling flows may be taking up different space inside the cyclone gasifier. In other words, unused space, i.e. space inside the cyclone gasifier which would not comprise any particulate fuel and/or oxidant (in the case where there would be only one swirling flow) and thereby not contributing to said gasification process, is reduced by having at least two different inlets being arranged and configured to create at least two different swirling flows.

[0011] According to at least a first aspect of the present inventive concept, a cyclone gasifier is provided. The cyclone gasifier comprises:

- a gasification chamber having an inner wall comprising an at least partly curved surface,
- a first inlet and a second inlet, said first inlet being arranged and configured to inject a first mixture of oxidant and particulate fuel at least partly towards said curved surface of said gasification chamber such that a first swirling flow of said first mixture is established and allowed to propagate through at least a part of said gasification chamber, whereby, in a thermochemical reaction of said first mixture syngas is generated,
- a syngas exit pipe arranged at least partly inside said gasification chamber, said syngas exit pipe having an opening arranged inside said gasification chamber for receiving said syngas,

wherein said second inlet is arranged and configured to inject a second mixture of oxidant and particulate fuel at least partly towards said curved surface of said gasification

chamber such that a second swirling flow of said second mixture is established and allowed to propagate through at least a part of said gasification chamber, said second swirling flow being at least partly offset in its propagation compared to said first swirling flow.

[0012] Hereby, the cyclone gasifier can be made more compact, while maintaining the same efficiency (i.e. maintaining the same syngas production relative to used fuel). Alternative, the efficiency of the cyclone gasifier can be increased while maintaining the same size of the cyclone gasifier.

[0013] By having a first swirling flow with a first propagation in at least a part of the gasification chamber, and having a second swirling flow with a second propagation in at least a part of the gasification chamber, the first propagation being different compared to the second propagation in that the first swirling flow is at least partly offset to the second swirling flow, the space inside the cyclone gasifier (i.e. the space of the gasification chamber) is better utilized.

[0014] It should be noted that the term offset is to be interpreted such that the second swirling flow has a propagation in a part of the gasification chamber which at least partly, is different from the propagation of the first swirling flow. In other words, the second swirling flow of the second mixture is present in a space inside the gasification chamber where the first swirling flow is not present.

[0015] For example, if the second swirling flow is injected into the first swirling flow, and subsequently follows the first swirling flow, the first and the second swirling flows are not offset to each other. However, if the second swirling flow, being the flow injected from the second inlet arranged downstream of said first inlet, is injected into the gasification chamber in such a way that it at least partly, do not follow the first swirling flow, being the flow injected from the first inlet, the first and the second swirling flows are offset to each other.

[0016] In other words when stating that two at least partly different swirling flows are offset compared to each other, it is meant that the propagation of the two swirling flows in said gasification chamber are different. A swirling flow may be described as a flow with a helical or a thread-like propagation having a centerline. Thus, when stating that the swirling flows is offset compared to each other, according to one example a centerline of said first swirling flow propagation is vertically and/or radially offset compared to a centerline of the second swirling flow propagation.

[0017] When stating that the first swirling flow of the first mixture is established and allowed to propagate through at least a part of said gasification chamber, and that the second swirling flow of said second mixture is established and allowed to propagate through at least a part of said gasification chamber, it should be noted that the respective "at least a part of said gasification chamber" may be the same part of the gasification chamber, i.e. along the same height or length of the gasification

chamber, or at least partly different parts of the gasification chamber, i.e. along at least a different height or length of the gasification chamber. For example, the first swirling flow of the first mixture may be established and allowed to propagate through a first propagation part of the gasification chamber, and the second swirling flow of the second mixture may be established and allowed to propagate through a second propagation part of the gasification chamber. The first propagation part may be the same, or substantially the same as the second propagation part, if e.g. the first and the second inlets are arranged at the same, or substantially the same, z-coordinate of the gasification chamber. According to at least one example embodiment, the first propagation part is at least partly overlapping with the second propagation part, and at least partly different. In other words, the first propagation part is extending along a certain height or length of the gasification chamber, while the second propagation part is extending along at least partly the same height or length of the gasification chamber, at least partly along a different height or length of the gasification chamber.

[0018] It should be noted that the second mixture in said second swirling flow also undergoes a thermochemical reaction which produces at least syngas. Thus, according to at least one example embodiment, a thermochemical reaction of said second mixture generates at least syngas.

[0019] In order for the cyclone gasifier to reach the temperature needed for the particulate fuel and oxidant to undergo a thermochemical reaction, the gasification chamber is preheated. This may e.g. be accomplished by using the available inlets, i.e. the first and/or the second inlet, to inject a fuel together with an oxidant in order to provide for an exothermic reaction between the fuel and the oxidant. This exothermic reaction will thus pre-heat the cyclone gasifier and the gasification chamber. Alternatively, or additionally, the gasification chamber may be pre-heated by the use of an oil boom. Hereby, oil is burnt inside the gasification chamber for a few hours in order to pre-heat the cyclone gasifier and the gasification chamber. Preferably, the gasification chamber is pre-heated to a temperature of around 900 °C, which is close to the operating temperature of the cyclone gasifier.

[0020] It should be noted that the inner wall of the gasification chamber is at least partly curved, e.g. by being cylindrically shaped such that a part of said curved wall forms part of a cylinder. According to at least one example embodiment, a cross section of said gasification chamber is circular (said cross section being perpendicular to an axis A extending along the z-direction as explained below). According to at least one example embodiment, a part of said inner wall is cylindrically shaped. According to at least one example embodiment, a part of the inner wall of said gasification chamber is formed as a part of cylinder. According to at least one example embodiment, the inner wall of said gasification chamber is formed as a part of a cylinder, such as e.g. the whole inner wall of said gasification chamber.

[0021] The first and/or the second inlet may be arranged and configured to inject its respective mixture in such a way that the respective first and second swirling flows propagates throughout the gasification chamber, such as e.g. along a majority of, or the whole of the gasification chambers length (or height).

[0022] It should be noted that said first mixture and said second mixture may be similar to each other. According to at least one example embodiment, the first mixture and the second mixture are the similar, or substantially similar, e.g. have the same proportions of oxidant and particulate fuel, and the same type of oxidant, such as e.g. air, and the same sort of particulate fuel, e.g. biofuel. According to at least one example embodiment, the first mixture and the second mixture are different. According to at least one example embodiment, the proportions of oxidant and particulate fuel is the same for the first and the second mixtures, but the oxidant and/or the particulate fuel is different. According to at least one example embodiment, the oxidant and/or the particulate fuel is/are the same for the first and the second mixtures, but the proportions of the oxidant and the particulate fuel is different for the first and the second mixtures.

[0023] According to at least one example embodiment, said oxidant is air. According to at least one example embodiment, said particulate fuel is one or more of the following: biomass, biofuel, coal, wood, agricultural residues such as e.g. husk, digestate, barch, straw, peat, fibre residue. According to at least one example embodiment, said particulate fuel comprises particles with a particle size of less than 3 mm and a moisture ratio of not more than 20 wt%. For example, 80 % or more of said particulate fuel comprises particles with a particle size of less than 3 mm and a moisture ratio of not more than 20 wt%. According to at least one example embodiment, said first and/or said second mixtures comprises an additional substance besides oxidant and particulate fuel, such as e.g. and inert substance or e.g. sand or carbon dioxide.

[0024] According to at least one example embodiment, the gasification chamber of said cyclone gasifier is defined by cylindrical coordinates, i.e. said gasification chamber is having an extension in a radial direction p , an extension in an azimuth angle direction ϕ , and an extension in a z-direction being perpendicular to a p , ϕ -plane defined by the radial and azimuth angle directions, and said first inlet is arranged and configured to inject said first mixture, and/or said second inlet is arranged and configured to inject said second mixture, in both the radial direction and in the azimuth angle direction of said gasification chamber,

and/or said first inlet is arranged and configured to inject said first mixture, and/or said second inlet is arranged and configured to inject said second mixture, in at least partly said z-direction of said gasification chamber.

[0025] The z-direction of the gasification chamber may also be used to define the height (or the length) of the

gasification chamber, e.g. when the cyclone gasifier is arranged in a vertical position. In other words a distance in the z-direction is a distance along the height (or length) of the gasification chamber. As the spatial extension of the cyclone gasifier may also be defined by cylindrical coordinates, and as preferably, the z-direction of the gasification chamber coincides with the z-direction of the cyclone gasifier, the height of the cyclone gasifier is extending in the same direction as the height of the gasification chamber.

[0026] According to at least one example embodiment, said first and said inlet is arranged at different z-coordinates of the gasification chamber, i.e. the first and the second inlets are arranged at different heights. For example, the first inlet may be arranged between 10 cm and 100 cm, such as e.g. between 20 cm and 80 cm or e.g. between 20 cm and 40 cm or e.g. between 10 cm and 20 cm, from the second inlet in the z-direction. According to at least one example embodiment, the first inlet is arranged between 1 % and 10 %, such as e.g. between 1 % and 5 % or between 5 % and 10 % from the second inlet in the z-direction, determined as a ratio between the distance in the z-direction between the first and the second inlet, and the height or length of the gasification chamber.

[0027] According to at least one example embodiment, said first inlet is arranged at the same height as said second inlet, i.e. both said first inlet and said second inlet are arranged at the same, or substantially the same, z-coordinate in the cylindrical coordinate system of the gasification chamber. For example, the z-coordinate of the position of the first inlet is within 1 % within the z-coordinate of the position of the second inlet.

[0028] According to at least one example embodiment, the azimuth angle ϕ between the first inlet and the second inlet, such as e.g. between a centre of the first inlet and a centre of the second inlet, is between 5° and 355°, or between 15° and 340°, or between 30° and 300°, or between 90° and 270° or between 165° and 195° such as e.g. 180°. Additionally, the first inlet and the second inlet may be arranged at the same or different z-coordinate of the gasification chamber.

[0029] According to at least one example embodiment, the first and/or the second inlet is arranged and configured to inject its mixture of oxidant and particulate fuel into said gasification chamber such that said first swirling flow and/or said second swirling propagates at least partly coaxial with said syngas exit pipe. According to at least one example embodiment, said first swirling flow and/or said second swirling propagate at least partly radially outwardly of said syngas exit pipe. According to at least one example embodiment, said first inlet and said second inlet is arranged at a respective z-coordinate which is higher compared to the z-coordinate of the opening of the syngas exit pipe. In other words, the first and the second inlets are arranged at a larger height as compared to the opening of the syngas exit pipe. According to at least one example embodiment, both first inlet and said

second inlet is facing said gasification chamber at a height at where the syngas exit pipe is arranged. According to at least one example embodiment, said first inlet is arranged higher in the gasification chamber compared to said second inlet, i.e. said first inlet is arranged upstream of said second inlet.

[0030] It should be noted that a swirling flow generally follows a trajectory, or a helical path, through at least a part of the gasification chamber. For example, along the trajectory of the first swirling flow, i.e. in the centre of the first swirling flow, a high degree of the first mixture of particulate fuel and oxidant is present. Further away from the centre of the first swirling flow, e.g. further away in the z-direction, a lesser degree of the first mixture of particulate fuel and oxidant is present. Furthermore, along e.g. the z-direction, during one revolution of the first swirling flow along its trajectory or helical path, a space, i.e. a space in the z-direction, is present where no, or very little of the first mixture is present, i.e. a space where the first swirling flow is not present.

[0031] In order to clarify, the swirling flow may be seen as a whirling thread or a threaded screw following said trajectory of the swirling flow. The trajectory is thus coherent with the centre of the whirling thread or threaded screw. Thus, in a portion of the swirling flow, i.e. in and near the centre of the swirling flow, a high degree of the mixture of particulate fuel and oxidant is present. Further away from the centre of the swirling flow, less of the mixture of particulate fuel and oxidant is present, and in between two centres of the swirling flow in one revolution of the swirling flow (i.e. along e.g. the z-direction between two centres in one revolution of the whirling thread or the threaded screw), no or very little of the mixture of particulate fuel and oxidant is present. Thus, in relation to the first mixture and the first swirling flow, there is a space along e.g. the z-direction inside the gasification chamber between two centres in one revolution of the first swirling flow, which is not, or very little, utilized for the gasification process of the first mixture.

[0032] Hereby, said second mixture of particulate fuel and oxidant injected by the second inlet in order to form the second swirling flow may be arranged to propagate inside at least a part of the gasification chamber at least partly in the space between two centres in one revolution of the first swirling flow, where no, or very little of the first mixture is present. In other words, in the example above, the propagation of said first swirling flow is offset compared to the propagation of said second swirling flow. According to at least one example embodiment, the trajectory of the first swirling flow following a helical path through at least a part the gasification chamber is offset as compared to the trajectory of the second swirling flow following a helical path through at least a part the gasification chamber.

[0033] According to at least one example embodiment, the propagation of said first swirling flow may be offset compared to the propagation of said second swirling flow in a different manner. For example, the propagation of

said first swirling flow may be offset compared to the propagation of said second swirling flow by being offset in the radial direction, e.g. by introducing different physical paths inside the gasification chamber for which the swirling flows follows.

[0034] It should be noted that at least the particulate fuel is prone to be pushed to the inner wall of the gasification chamber by the centrifugal force. Thus, the trajectories of the first and the second swirling flows may extend along the gasification chamber close to the inner wall of the gasification chamber.

[0035] According to at least one example embodiment, said first inlet is arranged and configured to inject said first mixture in solely the azimuth angle direction, e.g. in a tangential direction of said gasification chamber, and said second inlet is arranged and configured to inject said second mixture in the azimuth angle direction and the radial direction and/or the z-direction of said gasification chamber.

[0036] According to at least one example embodiment, said second inlet is arranged and configured to inject said second mixture in solely the azimuth angle direction, e.g. in a tangential direction of said gasification chamber, and said first inlet is arranged and configured to inject said first mixture in the azimuth angle direction and the radial direction and/or the z-direction of said gasification chamber.

[0037] According to at least one example embodiment, said second inlet is arranged and configured to inject said second mixture at least partly into said first swirling flow in order to stir said first and said second mixtures in order to enhance said thermochemical reaction.

[0038] For example, the second inlet may be arranged to inject said second mixture such that the trajectory of the second swirling flow is close to the trajectory of said first swirling flow. Hereby, a part of said second swirling flow will interfere with a part of first swirling flow, while a part of said second swirling flow will not interfere with any part of first swirling flow.

[0039] According to at least one example embodiment, the second inlet is arranged to inject said second mixture at least partly into said first swirling flow in order to stir the first and the second mixtures outside of said second inlet.

[0040] According to at least one example embodiment, said second inlet is arranged and configured to inject said second mixture into said gasification chamber such that said second swirling flow of said second mixture is allowed to propagate through said at least part of said gasification chamber independently of said first swirling flow.

[0041] For example, said second inlet may be arranged to inject said second mixture to establish said second swirling flow in such a way that it propagates through (at least a part of) the gasification chamber without ever interfering with said first swirling flow. Hereby, the behaviour of the first swirling flow is independent compared to said second swirling flow.

[0042] According to at least one example embodiment,

each of said first and said second swirling flows is having a pitch and a lead, wherein the lead of said first swirling flow is different from the lead of said second swirling flow, and wherein the pitch of said first swirling flow is different from the pitch of said second swirling flow.

[0043] Thus, according to at least one example embodiment, the propagation of the first swirling flow is offset compared to the propagation of the second swirling flow by that the lead and pitch of the first swirling flow is different compared to the lead and pitch of the second swirling flow. According to at least one example embodiment, the trajectory of the second swirling flow may cross the trajectory of the first swirling flow in at least parts of the gasification chamber, while in different parts of gasification chamber, the trajectory of the second swirling flow do not cross the trajectory of the first swirling flow.

[0044] According to at least one example embodiment said syngas exit pipe further comprises an outer wall arranged at least partly inside said gasification chamber, and wherein said outer wall is an obstructing surface for at least one of said first and said second swirling flows.

[0045] Hereby, the first and or the second mixtures of the first and the second swirling flows respectively, may be further mixed in order to enhance the thermochemical reaction.

[0046] According to at least one example embodiment, said first inlet is arranged and configured to direct at least a part of said first mixture, and/or said second inlet is arranged and configured to direct at least a part of said second mixture, towards said syngas exit pipe in order to stir said first and/or said second mixture in order to enhance said thermochemical reaction.

[0047] Hereby, the first and or the second mixtures may be mixed prior to the creation of the first and the second swirling flows, respectively. This in order to enhance the thermochemical reaction.

[0048] According to at least one example embodiment, said first inlet is arranged and configured to direct at least a part of said first mixture, and/or said second inlet is arranged and configured to direct at least a part of said second mixture, towards said outer wall of the syngas exit pipe in order to stir said first and/or said second mixture in order to enhance said thermochemical reaction.

[0049] According to at least one example embodiment, said gasification chamber comprises a first portion and a second portion, said first portion being arranged to receive said first and/or said second mixture, and said second portion being arranged for receiving ash particles stemming from said thermochemical reaction.

[0050] Thus, according to at least one example embodiment, the gasification chamber may be divided into at least two portions, a first portion (which may be referred to as an upper portion when the cyclone gasifier is arranged in a vertical arrangement) where the majority of the gasification of the particulate fuel occurs, and a second portion (which may be referred to a lower portion when the cyclone gasifier is arranged in a vertical arrangement) arranged in fluid connection with said first

portion. In said second portion, a majority of the ashes are separated from the syngas although some gasification of the particulate fuel may occur also in said second portion. Thus, said second portion may be referred to as an ash-collecting portion of said gasification chamber of said cyclone gasifier. It should be noted that some separation of the ashes may also occur in said first portion.

[0051] According to at least one example embodiment, said first portion may be referred to a gasification portion of the gasification chamber of the cyclone gasifier. In other words, inside said first portion of said gasification chamber, said particulate fuel is gasified while some separation of the ashes may also occur. Inside said second portion, or said ash-collecting portion, the ashes are separated from the syngas while some gasification of the particulate fuel may also occur.

[0052] According to at least one example embodiment, said first portion is having an inner wall is at least partly curved, e.g. by being cylindrically shaped such that a part of said curved wall forms part of a cylinder. According to at least one example embodiment, a cross section of said first portion is circular (said cross section being perpendicular to an axis A extending along the z-direction). According to at least one example embodiment, a part of said inner wall of said first portion is cylindrically shaped. According to at least one example embodiment, a part of the inner wall of said first portion is formed as a part of cylinder. According to at least one example embodiment, the inner wall of said first portion is formed as a part of a cylinder, such as e.g. the whole inner wall of said first portion.

[0053] According to at least one example embodiment, said second portion is having an inner wall which forms part of a cone or a frustum, e.g. by being conically shaped, or at least partly conically shaped. For example said second portion may be formed as a truncated cone or as a frustum. According to at least one example embodiment, the inner wall of the gasification chamber is at least partly forming a part of a cylinder, i.e. by that the first portion is cylindrically shaped, i.e. the inner wall along the first portion is curved to form a cylinder, and the gasification chamber is at least partly conically shaped, i.e. by that the second portion is formed as a frustum, i.e. the inner wall along the second portion is curved to form a frustum, or a part of a cone.

[0054] According to at least one example embodiment, said first inlet is arranged upstream of said second inlet, and wherein a ratio of the distance between said first inlet and said second inlet in the axial direction, and the length of the first portion of the gasification chamber is between 0 % and 20 %.

[0055] That is, a distance between the first and the second inlets in the z-direction compared to the height (or length) of the first portion of the gasification chamber is between 0 % and 20 %. According to at least one example embodiment, a distance between the first and the second inlets in the z-direction compared to the height (or length) of the gasification chamber is between 0 %

and 10 %.

[0056] Hereby, the cyclone gasifier can be made more compact as the space of the gasification chamber is better utilized. In other words, by arranging the first and the second inlet close to each other, i.e. within 20 % as stated above, the space of the gasification chamber taken up by the first and the second swirling flows is improved.

[0057] According to at least one example embodiment, the first inlet is arranged between 1 % and 50 %, such as e.g. between 1 % and 5 % or between 5 % and 10 % or between 10 % and 15 % or between 15 % and 20 %, or between 20 % and 30 %, or between 30 % and 40 %, or between 40 % and 50 %, from the second inlet in the z-direction, determined as a ratio between the distance in the z-direction between the first and the second inlet, and the height or length of the first portion of the gasification chamber.

[0058] The height of both the cyclone gasifier and the gasification chamber may be described as increasing in a direction as seen from the ash-collecting portion towards the gasification portion.

[0059] According to at least one example embodiment, said second portion is arranged distal to said opening of said syngas exit pipe.

[0060] According to at least one example embodiment, said second portion is arranged distal to said first and/or said second inlet.

[0061] According to at least one example embodiment, said second portion is tapering, e.g. by being conically shaped.

[0062] For example, said second portion may be tapering in a direction away from said first portion, and/or tapering in a direction away from said opening of said syngas exit pipe.

[0063] According to at least one example embodiment, said first and/or said second inlet has a non-circular cross-section.

[0064] Hereby, some initial mixing of the mixture of particulate fuel and oxidant may occur, e.g. prior to the forming of the first and second swirling flows.

[0065] It should be understood that the production of a swirling flow (such as e.g. the first and the second swirling flows), or vortex-like flow inside the cyclone gasifier is dependent on e.g. the force of gravity, the rate of which the mixture of particulate fuel and oxidant is injected into the gasification chamber (i.e. the velocity of the injection of the first and second mixtures), the size of the inlet (i.e. the size of the first and second inlets), the inner diameter of the gasification chamber, and the shape of inner wall of the gasification chamber (or the shape of the first portion of the gasification chamber as explained above). For example all, or at least some, of the following design criteria are used in order for a swirling flow to be established inside the cyclone gasifier: arranging the inlet, such as the first and/or the second inlet, in such a way that the velocity of the mixture, e.g. the first and/or the second mixture, during the injection of the mixture into the gasification chamber is between 15 m/s and 200 m/s,

such as e.g. between 20 m/s and 175 m/s, or between 25 m/s and 150 m/s, or between 30 m/s and 130 m/s, or between 50 m/s and 100 m/s; arranging the cyclone gasifier in a vertical set-up, i.e. where the force of gravity is acting in a direction from the first portion of the gasification chamber towards the second portion of the gasification chamber; having an inlet, such as the first and/or the second inlet, of the size, such as the effective diameter, or the diameter, of between 30 mm and 120 mm, or between 40 mm and 100 mm, or between 50 mm and 75 mm; having a gasification chamber of the size, such as the effective diameter or the diameter, of between 500 mm and 3000 mm, such as e.g. between 500 mm and 2000 mm, or between 500 mm and 1500 mm, e.g. of 750 mm, or between 1000 mm and 1500 mm; having an inner wall of the gasification chamber (or the having an inner wall of the first portion of the gasification chamber as explained above) which is, at least partly curved, e.g. by being cylindrically shaped or at least partly, or fully, shaped as a part of a cylinder.

[0066] In other words the arrangement of said inlet, such as e.g. the first and/or the second inlet, together with the arrangement of said gasification chamber, such as e.g. the at least partly curved shaped inner wall of the gasification chamber, provides for a condition where a swirling flow is allowed to be established and propagate through at least a part of the gasification chamber.

[0067] By providing for a velocity of the mixture over 100 m/s, a grinding effect (which may be referred to as an air grinding effect) of the particulate fuel inside the cyclone gasifier is provided for.

[0068] According to at least a second aspect of the present inventive concept, a system for producing a combustible gas is provided. The system comprises:

- a cyclone gasifier for producing at least syngas, according to the first aspect of the present inventive concept,
- a heat exchanger for receiving the syngas from said cyclone gasifier, said heat exchanger being arranged to cool the syngas;
- a cyclone separator for receiving the syngas from said heat exchanger, said cyclone separator being arranged to separate particulate matter from the syngas;
- an oil scrubber for receiving the syngas from said cyclone separator, said oil scrubber being arranged to direct the syngas through an oil mist in order to remove tar from the syngas, whereby a combustible gas is produced.

[0069] The heat exchange may e.g. cool the syngas from 900 °C to 400 °C. The cyclone separator may e.g. be a multicyclone arranged to separate any particulate matter which followed the syngas from the cyclone gasifier (the particulate matter being commonly referred to as "carry-over").

[0070] The gas leaving the oil scrubber is a combusti-

ble gas which may be combusted in a combustion engine or a gas turbine for e.g. producing electricity.

[0071] By using a cyclone gasifier in accordance with the first aspect of the present inventive concept, the other components can be made smaller as the efficiency of the cyclone gasifier is better as compared to prior art solutions. For example, as the ash contains less unconverted particulate fuel the more of the particulate fuel is refined to syngas.

[0072] According to at least one example embodiment, the system is further provided with an electrostatic filter and/or a dryer/dehumidifier and/or a particulate centrifuge.

[0073] According to at least a third aspect of the present inventive concept, a method for gasifying a mixture of oxidant and particulate fuel inside a cyclone gasifier having a gasification chamber having an inner wall comprising an at least partly curved surface, and at least a first and a second inlet is provided for. The method comprises the steps of:

- injecting a first mixture of oxidant and particulate fuel at least partly towards said curved surface of said gasification chamber through said first inlet such that a first swirling flow of said first mixture is formed and allowed to propagate in at least a part of said gasification chamber whereby said first mixture undergoes a thermochemical reaction in order to generate at least syngas,
- injecting a second mixture of oxidant and particulate fuel at least partly towards said curved surface of said gasification chamber through a second inlet such that a second swirling flow of said second mixture is formed and allowed to propagate in at least a part of said gasification chamber whereby said second mixture undergoes a thermochemical reaction in order to generate at least syngas,
- wherein in said step of injecting said second mixture, said second inlet injects said second mixture such that said second swirling flow becomes at least partly offset in its propagation compared to said first swirling flow.

[0074] Effects and features of this third aspect of the present inventive concept are largely analogous to those described above in connection with the first aspect of the inventive concept. Embodiments mentioned in relation to the first aspect of the present inventive concept are largely compatible with the third aspect of the inventive concept.

[0075] According to at least one example embodiment, said method comprises the step of providing particulate fuel having a particle size of less than 3 mm and a moisture ratio of not more than 20 wt%. For example, at least 80 % or more of the particle fuel has a particle size of less than 3 mm and a moisture ratio of not more than 20 wt%.

[0076] According to at least one example embodiment,

said cyclone gasifier further comprises a syngas exit pipe arranged at least partly inside said gasification chamber, and said method further comprises the steps of:

- directing said first mixture from said first inlet and/or directing said second mixture from said second inlet towards said syngas exit pipe in order to stir said first and/or said second mixture for enhancing said thermochemical reaction.

Brief description of the drawings

[0077] The present inventive concept will now be described in more detail, with reference to the appended drawings showing example embodiments, wherein:

Fig. 1 illustrates in cross section a cyclone gasifier according to at least one example embodiment;

Fig. 2 illustrates in cross section a cyclone gasifier with at least two swirling flows, according to at least one example embodiment;

Fig. 3 illustrates in cross section an arrangement of the first and the second inlet of the cyclone gasifier, according to at least one example embodiment.

Detailed description of the drawings

[0078] In the following description, the present inventive concept is described with reference to a cyclone gasifier comprising a gasification chamber and at least a first and a second inlet, each inlet being arranged for injecting a mixture of oxidant and particulate fuel into the gasification chamber. The present inventive concept is also described with reference to a system comprising such cyclone gasifier for producing a combustible gas and to a method for producing syngas using such cyclone gasifier.

[0079] Fig. 1 illustrates in cross section a cyclone gasifier 1 having a gasification chamber 5 with a first portion 10 and a second portion 80.

[0080] The gasification chamber 5 in fig 1 is at least partly defined by a curved surface or a curved inner wall 12. A first inlet 14 and a second inlet 16 are arranged in the upper part of the cyclone gasifier 1, and are formed as openings in the inner wall 12. The first inlet 14 is arranged to inject a first mixture of oxidant and particulate fuel into the gasification chamber 5, such as to inject the first mixture towards the curved inner wall 12, and the second inlet 16 is arranged to inject a second mixture of oxidant and particulate fuel into the gasification chamber 5, such as to inject the second mixture towards the curved inner wall. As explained in further detail below, the first and the second mixtures of air and particulate fuel undergo a thermochemical reaction inside said gasification chamber 5 due to the high temperature present in the gasification chamber 5. During the thermochemical reaction, at least ash particles and syngas are produced. In fig. 1, a syngas exit pipe 18 is arranged at least partly

inside the gasification chamber 5. The syngas exit pipe 18 has a syngas pipe inlet 20 arranged inside the gasification chamber 5 for receiving the produced syngas.

[0081] Preferably, the gasification of the particulate fuel and oxidant takes place at high temperature, e.g. over 900 °C. The high temperature, together with the low residence time of the fuel, has the advantage to keep the ashes from melting.

[0082] In the first portion 10 (which may be referred to as an upper portion 10 when the cyclone gasifier 1 is arranged in a vertical arrangement as seen in fig. 1) a majority of the gasification of the particulate fuel occurs. In the second portion 80 (which may be referred to a lower portion 80 when the cyclone gasifier 1 is arranged in the vertical arrangement), which is arranged in fluid connection with the first portion 10 a majority of the ashes are separated from the syngas although some gasification of the particulate fuel may occur. Thus, the second portion 80 may be referred to as an ash-collecting portion 80 of the gasification chamber 5 of the cyclone gasifier 1. It should be noted that some separation of the ashes may also occur in the first portion 10. Thus, the second portion 80 is arranged in fluid connection with the first portion 10, and is arranged to receive the ash particles. Second portion 80 comprises an outlet 82 through where the ash particles may exit the cyclone gasifier 1.

[0083] According to at least one example embodiment, the first portion 10 is having an inner wall 12a which is curved at e.g. by being at least partly cylindrically shaped. According to at least one example embodiment, the second portion 80 is having an inner wall 12b which is conically shaped, or at least partly conically shaped, e.g. the second portion 80 may be formed as a truncated cone or as a frustum. In this example embodiment, the inner wall 12 of the gasification chamber 5 is (at least partly) curved, such that the inner wall 12a of the first portion 10 forms a part of a cylinder, and such that the inner wall 12b of the second portion 80 forms a part of a cone, or a frustum.

[0084] The gasification chamber 5 may be defined by cylindrical coordinates. Thus the gasification chamber may be described as having an extension in a radial direction p , an extension in an azimuth angle direction ϕ , and an extension in a z -direction being perpendicular to a p , ϕ -plane defined by the radial and azimuth angle directions. A tangential direction is a direction following the azimuth angle direction ϕ , as seen from the periphery of the inner wall 12 of the gasification chamber 5.

[0085] In other words, a point P in the gasification chamber 5 may be defined by:

- the radial distance p from an axis, A, to the point P;
- the azimuth angle ϕ (being defined as the angle between a reference direction in a p , ϕ -plane and a direction from the axis A to the projection of point P on that p , ϕ -plane;
- the height z being the distance from the chosen p , ϕ -plane to the point P.

[0086] Optionally, or alternatively, the spatial extension of the cyclone gasifier 1 may be defined by cylindrical coordinates. Thus, the z -direction of the cyclone gasifier 1 may coincide with the z -direction of the gasification chamber 5, such that the height of the cyclone gasifier 1 is extending in the same direction as the height of the gasification chamber 5. The height of both the cyclone gasifier 1 and the gasification chamber 5 may be defined as increasing in a direction as seen from the second portion 80 towards the first portion 10 (i.e. when the cyclone gasifier is arranged in a vertical position).

[0087] As seen in fig. 1, the first inlet 14 and the second inlet 16 are arranged at different z -coordinates of the gasification chamber 5, preferably between 20 and 40 cm from each other. The difference in height between the first and the second inlets 14, 16, may also be described as a ratio between this distance to the length of the first portion 10. For example, having a height of the first portion 10 of 100 cm, the distance in the z -direction between the first and the second inlet 14, 16 is between 1 % and 15 %. In other words, the first inlet 14 and the second inlet 16 are both arranged in the different p , ϕ -planes.

[0088] The first inlet 14 and the second inlet 16 in fig. 1 are arranged in different positions in the inner wall 12. For example, the azimuth angle between the centre of the first inlet 14 and the centre of the second inlet 16 may be between 30° and 330°, such as e.g. 135° or 180° (see Fig. 3 for an example embodiment).

[0089] The function of the cyclone gasifier 1 will now be described in detail with reference to figs. 1 and 2.

[0090] The first inlet 14 is arranged and configured to inject the first mixture of oxidant and particulate fuel into said gasification chamber 5, at least partly towards said curved inner wall 12, 12a in such a way that a first swirling flow 100 of the first mixture is established and allowed to propagate through at least a part of the gasification chamber 5 (such as e.g. a part of or a majority of the first portion 10 of the gasification chamber 5 as seen in Fig. 1). The second inlet 16 is arranged and configured to inject a second mixture of oxidant and particulate fuel into said gasification chamber 5, at least partly towards said curved inner wall 12, 12a, in such a way that a second swirling flow 200 of the second mixture is established and allowed to propagate through at least a part of the gasification chamber 5 (such as e.g. a part of or a majority of the first portion 10 of the gasification chamber 5 as seen in Fig. 1). It should be noted that the propagation of swirling flows 100, 200 end somewhere in the gasification chamber 5, such as e.g. in the second portion 80. For example, each of the swirling flows 100, 200 may be divided into a stream of produced syngas (together with any "carry-over") which exits the cyclone gasifier 1 via the opening 20 of the syngas exit pipe 18, e.g. by being directed radially inwards of the swirling flows 100, 200, and towards said opening 20, and a stream of ashes which exits the cyclone gasifier through the outlet 82.

[0091] As seen in fig. 2, the propagation of the first swirling flow 100, i.e. the trajectory of the main flow of

the first mixture throughout at least a part of the gasification chamber 5, is different from the propagation of the second swirling flow 200, i.e. the trajectory of the main flow of the second mixture throughout at least a part of the gasification chamber 5. In other words, the first swirling flow 100 is offset compared to the second swirling flow 200. Hereby, the space inside the gasification chamber 5 is better utilized. In fig. 2, this offset characteristic between the first and the second swirling flows 100, 200 is exemplified by arranging the first inlet 14 to inject the first mixture such that the first swirling flow 100 is allowed propagate along a first trajectory 150 through the gasification chamber 5, and by arranging the second inlet 16 to inject the second mixture such that the second swirling flow 200 is allowed propagate along a second trajectory 250 through the gasification chamber 5 and where the second trajectory 250 passes through the gasification chamber 5 along a different path compared to the first trajectory 150.

[0092] By defining the first and the second swirling flows 100, 200 as each having a lead and a pitch, the lead and/or the pitch of the first swirling flow 100 may be the same as the lead and/or the pitch of the second swirling flow 200, respectively, as long as the propagation of the first swirling flow through the gasification chamber 5 is different compared to the propagation of the second swirling flow, as can be seen in fig. 2. That is the first swirling flow 100 is offset compared to the second swirling flow 200 as the first mixture of air and particulate fuel is injected into the gasification chamber 5 at another location as compared to the second mixture of air and particulate fuel injected by the second inlet 16.

[0093] It should be noted that the first and the second swirling flows 100, 200 may at least partly coincide with each other, and thereby cause an increased mix of oxidant and particulate fuel which may be beneficial for the thermochemical reaction inside the gasification chamber 5. The first and the second swirling flows 100, 200 may also propagate through the gasification chamber 5 independently of each other.

[0094] It should be noted that the injection of the first and the second mixtures of the first and the second inlets 14, 16, respectively, are adapted such that the first and the second swirling flows 100, 200 are allowed to be formed inside the gasification chamber 5. In other words, the first inlet 14, together with the inner wall 12 of the gasification chamber 5, are arranged and configured to produce the first swirling flow 100. The production of the swirling, or vortex-like, flow 100 of the first mixture is dependent on e.g. the rate of which the first mixture is injected into the gasification chamber 5 (i.e. the velocity of the injection of the first mixture), the size of the first inlet 14, the inner diameter of the gasification chamber 5 and the shape of the inner walls of the gasification chamber 5. Likewise the production of the swirling, or vortex-like, flow 200 of the second mixture is dependent on e.g. the rate of which the second mixture is injected into the gasification chamber 5 (i.e. the velocity of the injection of the

second mixture), the size of the second inlet 16, the inner diameter of the gasification chamber 5 and the shape of the inner walls of the gasification chamber 5.

[0095] As seen in fig. 3, the first inlet 14 may be arranged in a 180° relation to the second inlet 16 (i.e. the azimuth angle ϕ between the first and the second inlet is 180°). Hereby, the first and the second swirling flows 100, 200 may propagate through at least a part of the gasification chamber 5 while taking up different space inside the gasification chamber 5. Hence, the first and the second swirling flows 100, 200 are offset compared to each other.

[0096] As described above, along the respective propagation of the first and the second swirling flows 100, 200 inside the gasification chamber 5, the first and the second mixture of oxidant and particulate fuel undergo thermochemical reaction and at least ashes (ash particles) and syngas are produced. As a result of the swirling flows, the centrifugal force forces the ash particles towards the inner wall 12, 12a, 12b of the gasification chamber 5, allowing the ash particles to be transported further into the cyclone gasifier 1 and into the second portion 80 of the gasification chamber 5, where they may exit the cyclone gasifier 1 through the outlet 82.

[0097] While the cyclone gasifier is illustrated as having a particular configuration of e.g. a first and a second portion of the gasification chamber, and a first and a second inlet, and a syngas exit pipe arranged equidistantly to the inner wall at the same z-coordinate, one skilled on the art will recognize that such a cyclone gasifier may include more or fewer portions of different types, more inlets and a syngas exit pipe arranged differently. Indeed, one skilled in the art will recognize that the cyclone gasifiers illustrated in figs. 1-3 have been constructed to illustrate various aspects of the present inventive concept, and therefore is presented by way of illustration and not by way of limitation.

Claims

1. A cyclone gasifier comprising:

- a gasification chamber having an inner wall comprising an at least partly curved surface,
- a first inlet and a second inlet, said first inlet being arranged and configured to inject a first mixture of oxidant and particulate fuel at least partly towards said curved surface of said gasification chamber such that a first swirling flow of said first mixture is established and allowed to propagate through at least a part of said gasification chamber, whereby, in a thermochemical reaction of said first mixture syngas is generated,
- a syngas exit pipe arranged at least partly inside said gasification chamber, said syngas exit pipe having an opening arranged inside said

gasification chamber for receiving said syngas,

wherein

said second inlet is arranged and configured to inject a second mixture of oxidant and particulate fuel at least partly towards said curved surface of said gasification chamber such that a second swirling flow of said second mixture is established and allowed to propagate through at least a part of said gasification chamber, said second swirling flow being at least partly offset in its propagation compared to said first swirling flow.

2. A cyclone gasifier according to claim 1, wherein said gasification chamber is defined by cylindrical coordinates, i.e. said gasification chamber is having an extension in a radial direction p , an extension in an azimuth angle direction ϕ , and an extension in a z -direction being perpendicular to a p, ϕ -plane defined by the radial and azimuth angle directions, and wherein said first inlet is arranged and configured to inject said first mixture, and/or said second inlet is arranged and configured to inject said second mixture, in both the radial direction and in the azimuth angle direction of said gasification chamber, and/or wherein said first inlet is arranged and configured to inject said first mixture, and/or said second inlet is arranged and configured to inject said second mixture, in at least partly said z -direction of said gasification chamber.
3. A cyclone gasifier according to any one of the preceding claims, wherein said second inlet is arranged and configured to inject said second mixture at least partly into said first swirling flow in order to stir said first and said second mixtures in order to enhance said thermochemical reaction.
4. A cyclone gasifier according to any one claims 1-2, wherein said second inlet is arranged and configured to inject said second mixture into said gasification chamber such that said second swirling flow of said second mixture is allowed to propagate through said at least part of said gasification chamber independently of said first swirling flow.
5. A cyclone gasifier according to any one of the preceding claims, wherein each of said first and said second swirling flows is having a pitch and a lead, and wherein the lead of said first swirling flow is different from the lead of said second swirling flow, and wherein the pitch of said first swirling flow is different from the pitch of said second swirling flow.
6. A cyclone gasifier according to any one of the preceding claims, wherein said syngas exit pipe further comprises an outer wall arranged at least partly inside said gasification chamber, and wherein said out-

er wall is an obstructing surface for at least one of said first and said second swirling flows.

7. A cyclone gasifier according to any one of the preceding claims, wherein said first inlet is arranged and configured to direct at least a part of said first mixture, and/or said second inlet is arranged and configured to direct at least a part of said second mixture, towards said syngas exit pipe in order to stir said first and/or said second mixture in order to enhance said thermochemical reaction.
8. A cyclone gasifier according to any one of the preceding claims, wherein said gasification chamber comprises a first portion and a second portion, said first portion being arranged to receive said first and/or said second mixture, and said second portion being arranged for receiving ash particles stemming from said thermochemical reaction.
9. A cyclone gasifier according claim 8, wherein said first inlet is arranged upstream of said second inlet, and wherein a ratio of the distance between said first inlet and said second inlet in the axial direction, and the length the first portion of the gasification chamber is between 0 % and 20 %.
10. A cyclone gasifier according to any one of claims 8-9, wherein said second portion is arranged distal to said opening of said syngas exit pipe.
11. A cyclone gasifier according to any one of claims 8-10, wherein said second portion is tapering, e.g. by being conically shaped.
12. A cyclone gasifier according to any one of the preceding claims, wherein said first and/or said second inlet has a non-circular cross-section.
13. A system for producing a combustible gas, comprising:
 - a cyclone gasifier for producing at least syngas, according to any one of claims 1-12;
 - a heat exchanger for receiving the syngas from said cyclone gasifier, said heat exchanger being arranged to cool the syngas;
 - a cyclone separator for receiving the syngas from said heat exchanger, said cyclone separator being arranged to separate particulate matter from the syngas;
 - an oil scrubber for receiving the syngas from said cyclone separator, said oil scrubber being arranged to direct the syngas through an oil mist in order to remove tar from the syngas, whereby a combustible gas is produced.
14. A method for gasifying a mixture of oxidant and par-

ticulate fuel inside a cyclone gasifier having a gasification chamber having an inner wall comprising an at least partly curved surface, and at least a first and a second inlet, said method comprising the steps of:

- injecting a first mixture of oxidant and particulate fuel at least partly towards said curved surface of said gasification chamber through said first inlet such that a first swirling flow of said first mixture is formed and allowed to propagate in at least a part of said gasification chamber whereby said first mixture undergoes a thermochemical reaction in order to generate at least syngas, 5 10
 - injecting a second mixture of oxidant and particulate fuel at least partly towards said curved surface of said gasification chamber through a second inlet such that a second swirling flow of said second mixture is formed and allowed to propagate in at least a part of said gasification chamber whereby said second mixture undergoes a thermochemical reaction in order to generate at least syngas, 15 20
 - wherein in said step of injecting said second mixture, said second inlet injects said second mixture such that said second swirling flow becomes at least partly offset in its propagation compared to said first swirling flow. 25
15. A method gasifying a mixture of oxidant and particulate fuel inside a cyclone gasifier according to claim 14, said cyclone gasifier further comprises a syngas exit pipe arranged at least partly inside said gasification chamber, comprising the steps of: 30 35
- directing said first mixture from said first inlet and/or directing said second mixture from and said second inlet towards said syngas exit pipe in order to stir said first and/or said second mixture for enhancing said thermochemical reaction. 40 45 50 55

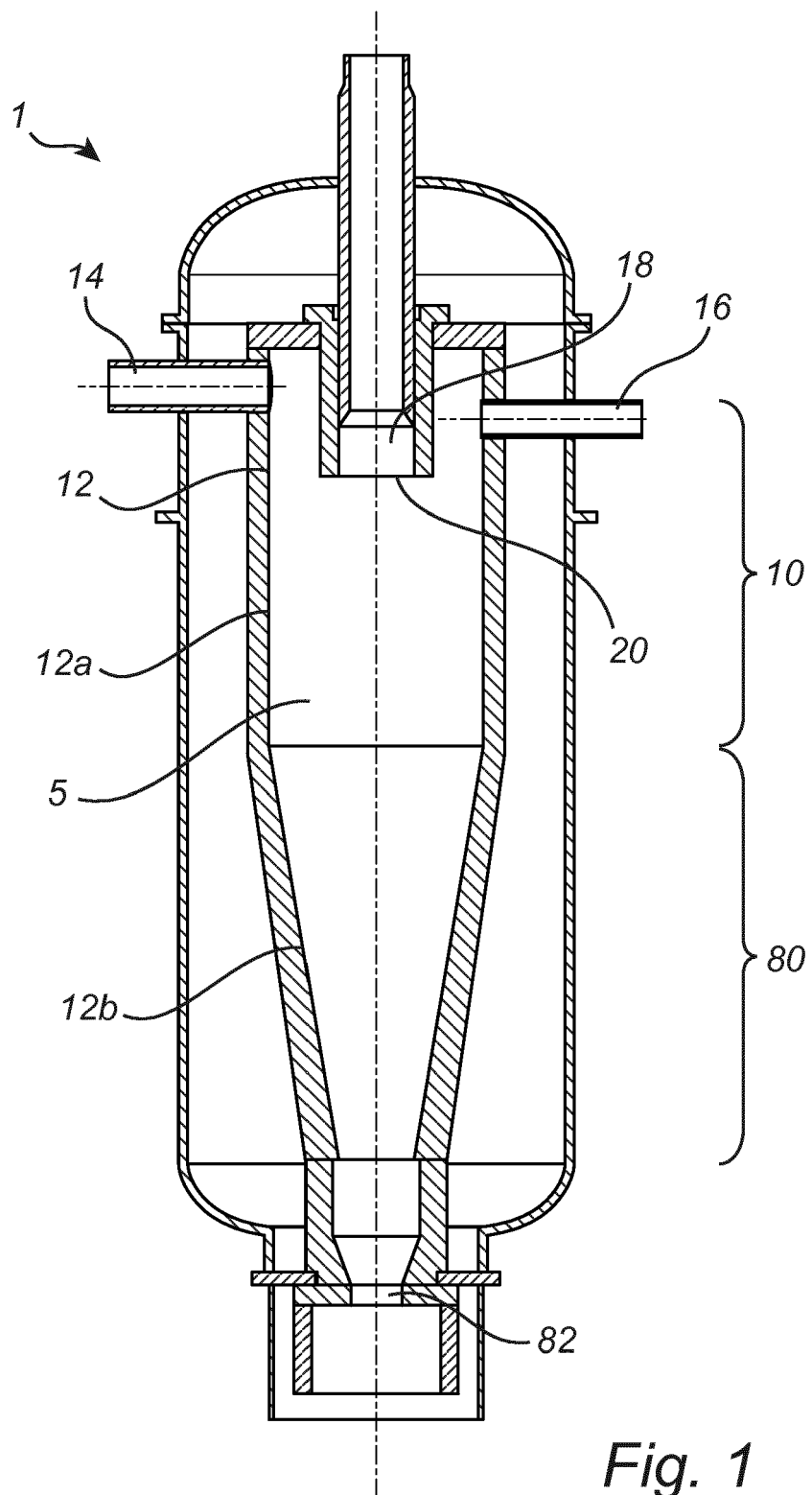


Fig. 1

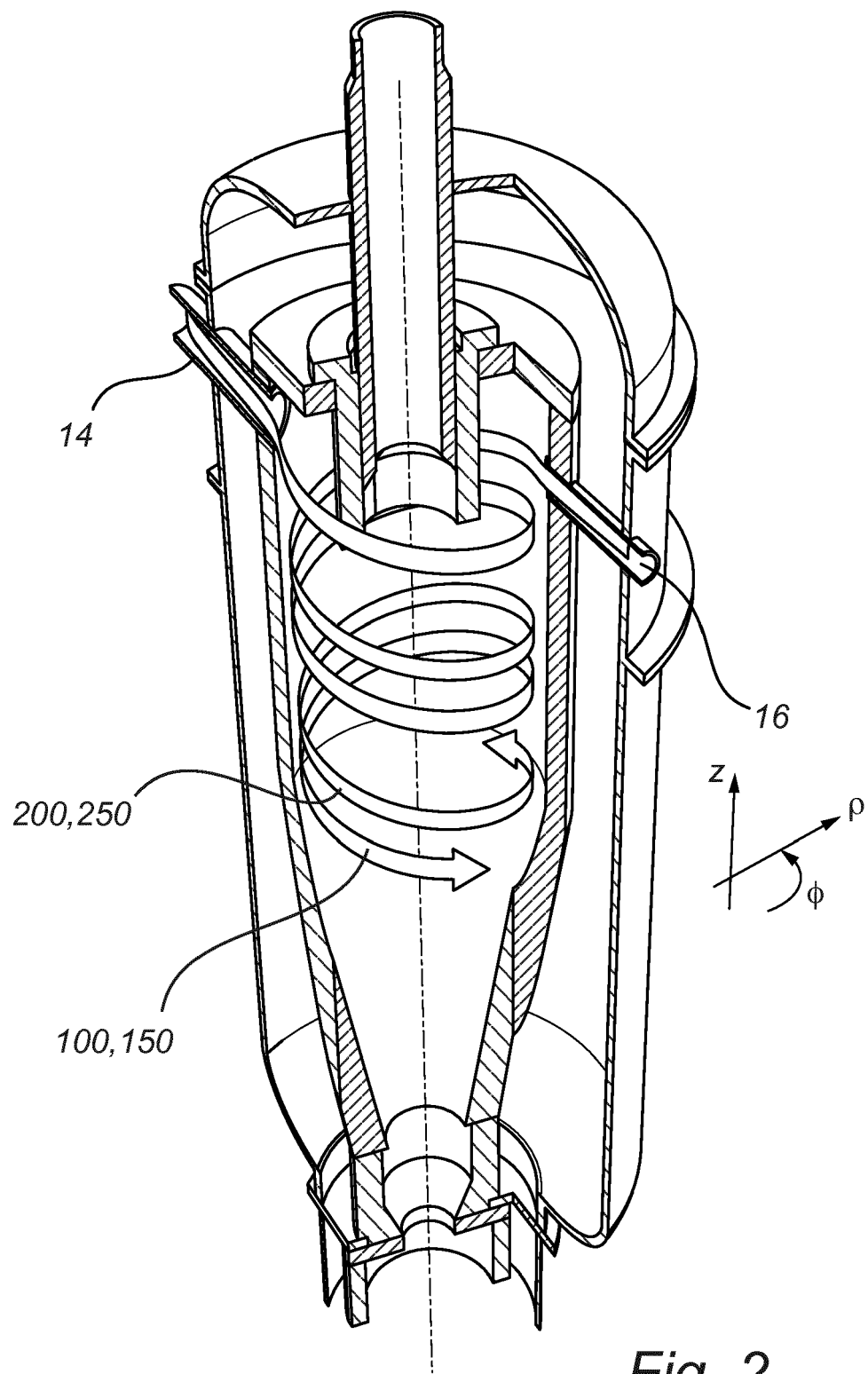


Fig. 2

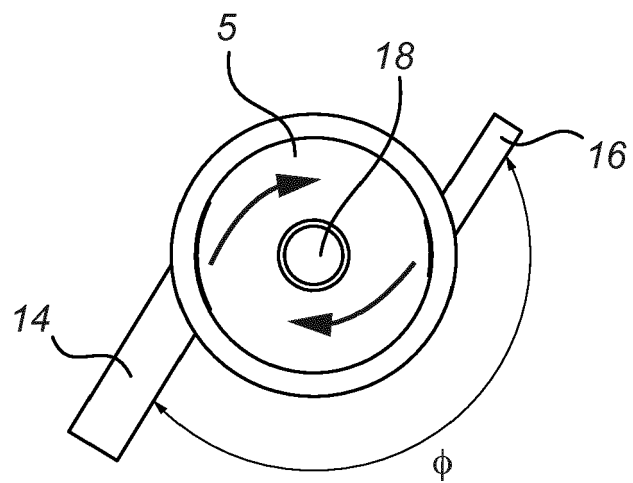


Fig. 3



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