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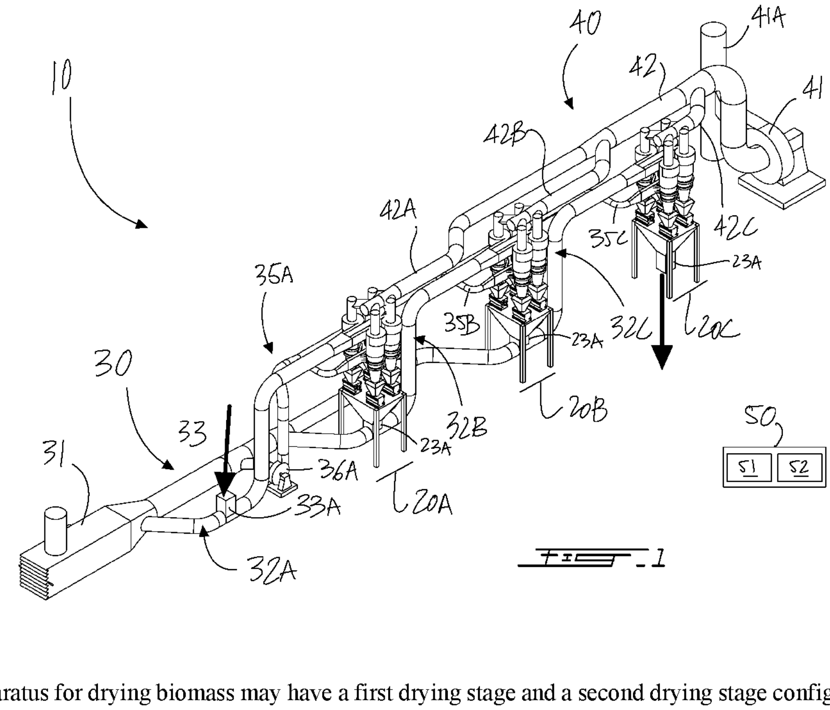

FIG. 1

(57) **Abstract:** An apparatus for drying biomass may have a first drying stage and a second drying stage configured to receive biomass and to expose the biomass to combustion gases to reduce a moisture content in the biomass, the first drying stage and the second drying stage being sealed. A pneumatic drying circuit is in fluid communication with the first drying stage and at least a second drying stage, the pneumatic drying conveyor configured to sequentially direct biomass from the first drying stage to the second drying stage using a flow of drying gases, the pneumatic drying circuit including a drying gas source configured to provide the drying gases, the pneumatic drying circuit connecting the first drying stage and at least a second drying stage to the drying gas source in a parallel arrangement. An exhaust circuit is in fluid communication with the first drying stage and the second drying stage for exhausting moisture from the first drying stage and the second drying stage.

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METHOD AND APPARATUS FOR DRYING BIOMASS

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application claims the benefits of United States Patent Application No. 63/506,844, filed on June 8, 2023, the entire contents of which are incorporated herein by reference.

FIELD OF THE APPLICATION

[0002] The present application relates to the transformation of biomass into products of increased energy density (e.g., combustion products) and increased carbon content, and more particularly to a method and apparatus for drying biomass.

BACKGROUND OF THE ART

[0003] In the torrefaction of biomass, products of increased energy density and increased carbon content are produced by the thermal treatment of the biomass. Torrefaction may decompose reactive content from the biomass (e.g., hemicellulose content), remove volatile organic compounds (VOCs) and/or moisture from the biomass. Hence, the products resulting from torrefaction have an increased energy density and carbon content that is well suited for various applications, such as efficient combustion.

[0004] However, in order to increase the energy density of the biomass, energy must be expended. Thus energy expenditure in drying biomass must be reconciled with efficient use of energy while increasing the energy density, and thus any method and apparatus for drying biomass must be energy efficient. Moreover, the hermos-transformation of biomass into fuel may be problematic, for instance due to the flammable nature of the end product.

SUMMARY OF THE APPLICATION

[0005] It is therefore an aim of the present disclosure to provide a method and apparatus that addresses issues associated with the prior art, in drying biomass.

[0006] Therefore, in accordance with a first aspect of the present application, there is provided a method for drying biomass comprising: receiving biomass having a given moisture content; directing the biomass sequentially to at least a first drying stage and then to a second drying stage, the first drying stage and the second drying stage being sealed; feeding drying gases directly from one or more drying gas sources into the first drying stage to reduce moisture content of the biomass; and feeding drying gases directly from the one or more drying gas sources into the second drying stage to further reduce moisture content of the biomass.

[0007] Further in accordance with the first aspect, for instance, feeding drying gases to the drying stages includes exposing the biomass to a flow of drying gases in a cyclonic flow.

[0008] Still further in accordance with the first aspect, for instance, exposing the biomass to a cyclonic flow includes causing an annular vortex of the drying gases in the cyclonic flow to increase a residence time of the biomass in the cyclonic flow.

[0009] Still further in accordance with the first aspect, for instance, feeding drying gases to the drying stages includes feeding drying gases at a temperature ranging from 150 C to 300 C.

[0010] Still further in accordance with the first aspect, for instance, reducing the moisture content of the biomass includes reducing the moisture content to a range from 20% to 40%.

[0011] Still further in accordance with the first aspect, for instance, directing the biomass sequentially to at least a first drying stage and then to a second drying stage includes directing the biomass using the flow of drying gases.

[0012] Still further in accordance with the first aspect, for instance, feeding drying gases includes feeding combustion gases directly from one or more burners into the first drying stage and into the second drying stage.

[0013] Still further in accordance with the first aspect, for instance, feeding combustion gases includes feeding the combustion gases from a common one of the one or more burners.

[0014] Still further in accordance with the first aspect, for instance, directing the biomass sequentially to at least a first drying stage and then to a second drying stage, further includes directing the biomass to a third drying stage from the second drying stage; and feeding drying gases directly from the one or more drying gas sources into the third drying stage to further reduce moisture content of the biomass.

[0015] Still further in accordance with the first aspect, for instance, part of the drying gases may be exhausted in at least the first drying stage and the second drying stage.

[0016] Still further in accordance with the first aspect, for instance, feeding drying gases to the drying stages includes separating the biomass in at least two biomass streams in at least one of the drying stages, and exposing the biomass in the at least two biomass streams to the flow of drying gases.

[0017] Still further in accordance with the first aspect, for instance, the biomass of the at least two biomass streams may be received in a common hopper at an exit of the drying stage.

[0018] In accordance with a second aspect of the present disclosure, there is provided an apparatus for drying biomass comprising: a first drying stage and at least a second drying stage configured to receive biomass and to expose the biomass to drying gases to reduce a moisture content in the biomass, the first drying stage and the second drying stage being sealed; a pneumatic drying circuit in fluid communication with the first drying stage and at least a second drying stage, the pneumatic drying circuit configured to sequentially direct biomass from the first drying stage to the second drying stage using a flow of drying gases, the pneumatic drying circuit including a drying gas source configured to provide the drying gases, the pneumatic drying circuit connecting the first drying stage and at least a second drying stage to the drying gas source in a parallel arrangement; and an exhaust circuit in fluid communication with the first drying stage and the second drying stage for exhausting moisture from the first drying stage and the second drying stage.

[0019] Further in accordance with the second aspect, for instance, the first drying stage and the second drying stage each include at least one cyclonic bed reactor.

[0020] Still further in accordance with the second aspect, for instance, the first drying stage and the second drying stage each include a plurality of the at least one cyclonic bed reactor, the cyclonic bed reactors of the plurality being parallel to one another in the respective drying stage.

[0021] Still further in accordance with the second aspect, for instance, each of the drying stages includes a common hopper downstream of the plurality of cyclonic bed reactors for collecting biomass from the plurality of cyclonic bed reactors.

[0022] Still further in accordance with the second aspect, for instance, the cyclonic bed reactors have valves at a biomass outlet and at a connection with the exhaust circuit.

[0023] Still further in accordance with the second aspect, for instance, the pneumatic drying circuit includes a circuit portion being connected to the drying stages in parallel and configured for directly feeding drying gas to the drying stages.

[0024] Still further in accordance with the second aspect, for instance, at least a third drying stage may be configured to receive biomass and to expose the biomass to drying gases to reduce the moisture content in the biomass, and the pneumatic drying circuit is in fluid communication with third drying stage, the pneumatic drying circuit configured to sequentially direct biomass from the second drying stage to the third drying stage using the flow of drying gases.

[0025] Still further in accordance with the second aspect, for instance, the drying gas source is one or more burners, and the drying gas includes combustion gases.

[0026] In accordance with another aspect of the present application, there is provided an apparatus for drying biomass comprising: a first drying stage and at least a second drying stage configured to receive biomass and to expose the biomass to drying gases to reduce a moisture content in the biomass, the first drying stage and the second drying stage being sealed; a pneumatic drying circuit between the first drying stage and at least a second drying stage, the pneumatic drying conveyor configured to sequentially direct biomass from the first drying stage to the second drying stage using a flow of drying gases, the pneumatic drying circuit including a drying gas source configured to produce the drying gases, the pneumatic drying circuit connecting the first drying stage and at least a second drying stage to the drying gas source in a parallel arrangement; and an exhaust circuit in fluid communication with the first drying stage and the second drying stage for exhausting moisture from the first drying stage and the second drying stage.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] Fig. 1 is a perspective view of an apparatus for drying biomass in accordance with an aspect of the present disclosure;

[0028] Fig. 2 is a block diagram of the apparatus of Fig. 1; and

[0029] Fig. 3 is a flowchart of a method for drying biomass products in accordance with an aspect of the present disclosure.

DESCRIPTION OF THE EMBODIMENTS

[0030] Referring to Fig. 1, there is illustrated an apparatus for drying biomass at 10, referred to as apparatus 10. The apparatus 10 could also be referred to as a system, etc. The apparatus 10 is used to dry or pre-dry biomass feedstock to a suitable moisture content (e.g., about 25%, or in a range from 15% to 40%). Stated differently, the apparatus 10 reduces a moisture content in the biomass. In a variant, the apparatus 10 is used prior torrefaction of the biomass, or thermal transformation of the biomass, through the apparatus 10 could initiate the thermal transformation of the biomass. The biomass feedstock may be in any appropriate format, such as sawdust, pellets, flakes, chips, etc. The biomass may have been screened and passed through a sieve to be within a given range of granulometry. The moisture content of the biomass may be between 20% and 60%, with a range of optimal operation being between 25-40%. For instance, the biomass may originate from wood, agricultural residues, recycled wood, compost, etc. These are examples of biomass among others that may be used with the apparatus 10.

[0031] The apparatus 10 may have one or more drying stages 20, in which the biomass will be dried, with moisture removed and separated from the biomass at the drying stage(s) 20. The apparatus 10 may further include a pneumatic drying circuit 30 (also referred to as a drying conveyor or pneumatic conveyor) to provide drying energy and motive flow for the biomass. The apparatus 10 may also have an exhaust circuit 40 to exhaust humidity, airborne particles, and/or combustion gases from the apparatus 10. A controller 50 having one or more processor unit 51 and non-transitory computer-readable memory 52 communicatively coupled to the processing unit and comprising computer-readable program instructions executable by the processing unit 51 for operating the apparatus 10 as described below. Sensors of any appropriate kind (e.g., thermocouples, pressure meters, manometers, moisture content sensors, etc) can be located at any appropriate position in the apparatus 10 to ensure its controlled operation.

[0032] According to an embodiment, the drying occurs by way of two of more of the drying stages 20, with Fig. 1 showing three such drying stages 20. There may be more than three.

[0033] The drying stages 20 are referred to commonly as drying stages 20 but are shown as drying stages 20A, 20B and 20C in Fig. 1. There may be additional drying stages 20, referred to herein as drying stage 20n. The drying stages 20A, 20B, 20C and 20n are sequential in that biomass first goes through drying stage 20A, to then move on to the subsequent drying stage 20B, and so forth and so on. It may be said that the drying stages 20 are in series relative to the biomass flow, as the biomass travels from drying stage to the other drying stage according to the sequence. The conveying between drying stages 20A, 20B, etc. is done by way of the pneumatic drying circuit 30. The pneumatic drying circuit 30 is tasked with conveying the biomass between drying stages 20 while exposing the biomass to drying gases (e.g., combustion gases, heated air, heated inert air, etc) in an embodiment of the present disclosure. Alternatively, a heated air stream may circulate in the pneumatic drying circuit 30. The heated air stream may be heated by coils, that may for example recuperate heat from a process. The heated air stream may use outdoor air, which may for example be mixed with combustion gases. In a variant, the gas stream is relatively inert, i.e., it has a low oxygen content or has no oxygen).

[0034] The exhaust circuit 40 is in fluid communication with the drying stages 20 to exhaust the combustion gases having been used to dry the biomass, along with airborne particles if present. The exhaust circuit 40 therefore contributes to a renewed gas flow of heated gases/drying gases into the apparatus 10, at it exhausts gas that may be compensated for by the pneumatic drying circuit 30. There may be more than one exhaust circuit 40, such as individual exhausts for each drying stage 20, embodied by chimneys at each stage 20 and/or each cyclonic bed reactor as described below.

[0035] The apparatus 10 includes one or more cyclonic bed reactors 21 (a.k.a., torrefaction reactor 21), with 12 of the cyclonic bed reactors being illustrated in Fig. 1. In the stages 20, the biomass is exposed to drying gases, during a predetermined minimum time of residency. The drying gases are at any appropriate temperature to have a drying effect on the biomass. As an example, the drying gases used for biomass are at a temperature ranging between 150 and 300°C, although temperatures outside this range may be appropriate as well in certain circumstances. As a result of the exposure to the drying gases, the biomass is dried: the level of moisture is substantially reduced. The temperature may be controlled based on the level of humidity in the biomass, the size of biomass granules or pellets (whatever the format of the biomass may be). Moreover, the temperature may be controlled so as to limit generation of VOCs.

[0036] Referring to Figs. 1 and 2, the drying stages 20 are shown as having a plurality of cyclonic bed reactors 21. In the illustrated embodiment, each of the drying stages 20 has four cyclonic bed reactors 21, but may have as little as one cyclonic bed reactor 21 and more than four cyclonic bed reactors 21.

[0037] As shown in Fig. 2, one of the drying stages 20 is shown, the drying stage 20 illustrated being any one of the stages 20A, 20B, 20C, 20n. The cyclonic bed reactors 21 are in parallel to one another in the drying stage 20. Each of the cyclonic bed reactors 21 may be said to have a cylindrical top 21A and a conical bottom 21B. Sustention ring(s) 21C may be on an outer surface of the cyclonic bed reactor 21 so as to inject additional combustion gases therein and contribute to maintaining the biomass in a cyclonic flow of drying gases.

[0038] The cyclonic bed reactors 21 may be similar in configuration to the filtration apparatus described in US patent application publication no. 2011/0239861, incorporated herewith by reference.

[0039] More specifically, in addition to the description provided herein the torrefaction reactor 21 may be broadly described as having a casing defining an inner cavity with an upper cylindrical portion, and a lower hopper portion connected to the upper cylindrical portion. The inlet is in the upper cylindrical portion for feeding a flow of gas and the biomass into the inner cavity. The inlet is positioned with respect to the casing to cause movement of the biomass in a downward spiral path in the casing. A solids outlet is at a bottom of the lower hopper portion for outletting the biomass from the casing. A gas outlet is in the upper cylindrical portion to exhaust gases from the casing. There is an annular arrangement of ports (i.e., a pair of sustentation rings, although one or more are possible) in a wall of the lower hopper portion or the cylindrical portion of the casing to inject gas into the inner cavity (e.g., drying gases). The ports are oriented so as to guide these other gas into following a path at least partially vertical when entering the inner cavity to disrupt the movement of the solids in the downward spiral path. It may be said that these ports, such as part of the sustentation ring(s) 21C, may cause or create an annular vortex of the gases in the cyclonic flow to increase a residence time of the biomass in the cyclonic flow. The annular vortex may have an upward vector at the entry of the cyclonic bed reactors 21. Hence, the gases injected through the ports of the sustentation ring may increase the residency time of the biomass in the reactor 21. For instance, the ports have a vertical component in their orientation, to guide the gases upwardly, and in the spiral path.

[0040] US patent application publication no. 2011/0239861 describes a filtration configuration at an upper end of the support wall of the filtration apparatus. The cyclonic bed reactor 21 may have a different filtration configuration, or even limited or no filtration.

[0041] The cyclonic bed reactors 21 of a common drying stage 20 may be separated from one another by way of an exhaust valve 22B or equivalent, and of a balancing damper 22A or other valve. The valve 22B may for example be a rotary airlock. In a variant, the cyclonic bed reactors 21 of a common drying stage 20 are calibrated to have the same airflow so as to receive a similar volume of biomass, to contribute to the uniformity of the process. The balancing dampers 22A of a same drying stage 20 may therefore be balanced, such as at start up or maintenance, to reach such a balanced condition, if desired. The devices 22A and 22B close off and/or restrict flow in the cyclonic bed reactors 21 so as to ensure that a flow within the cyclonic bed reactors 21 is controlled, and in order to preserve a flow direction within the apparatus 10.

[0042] Still referring to Fig. 2, the cyclonic bed reactors 21 may share a common hopper 23, or other similar receptacle or container. The hopper 23 defines an inner cavity that receives biomass exiting from the cyclonic bed reactors 21. The hopper 23 may funnel towards an outlet 23A (e.g., a chute) that may be closed off by a valve, airlock, or like device, though this is optional. The hopper 23 may merge into the pneumatic drying circuit 30. Pressures may be controlled to ensure that the biomass flows from the hopper 23 to the pneumatic crying circuit 30, as opposed to backflowing intp the hopper 23.

[0043] By the presence of the devices 22B, 23A (if present) or equivalents, the biomass circulating in the apparatus 10 will be exposed to high temperatures. In a variant, the airflow may be regarded as an inert environment of low oxygen, if combustion gases are used. The sealed rotary valves 22B, 23A or equivalents may limit the infiltration of a back airflow into the apparatus 10.

[0044] As an alternative to cyclonic bed reactors 21, the drying stages 20 may have drum dryers. In such drum dryers, the biomass is received in a rotating drum, the rotating drum having its rotational axis for example horizontal. Combustion gases or like drying gases may be fed to the drum. Unlike the cyclonic bed reactors 21 that may produce a continuous feed of dried biomass, a drum drier may produce batches of dried biomass. The cyclonic bed reactors 21 could be operated to produce batches of biomass as well.

[0045] In Figs. 1 and 2, the drying stages 20 are shown as being equivalent to one another in terms of size and configuration but can differ depending on capacity of the system, residence time desired for the biomass in the cyclonic bed reactors 21, etc. For example, a controller unit (e.g., controller 50) operating the apparatus 10 may inject more drying gases in some of the stages 20.

[0046] Still referring to Figs. 1 and 2, the pneumatic drying circuit 30 is shown having a drying gas source 31, such as a combustor or burner (e.g., including a stack of combustors 31), a process duct, conduit, network, etc with or without a heat exchanger to heat or condition a gas flow from the process. In a variant, the pneumatic drying circuit 30 does not include the burner(s) 31, but is instead connected to a combustion gas source or features a heat exchanger (e.g., heating coils). If the drying gas source 31 is a combustor, the combustor 31 may be of the type that receives a fuel supply or feed, and that burns the fuel. An outlet of the combustor 31 is connected to a manifold 32 that then diverges into circuit segments 32A, 32B, 32C. In a variant, there are as many circuit segments 32 as there are drying stages 20. In Fig. 1, circuit segment 32A is paired with drying stage 20A, circuit segment 32B is paired with drying stage 20B, and circuit segment 32C is paired with drying stage 20C. There may be different combustors 31 for each circuit segment 32, but in terms of cost and efficiency, a single combustor or drying gas source 31 may suffice and may be shared by the drying stages 20.

[0047] As observed, the biomass may enter the pneumatic drying circuit 30 via an inlet 33 that is in circuit segment 32A. A sealing device 33A, such as a rotary valve or like sas (e.g., feedscrew) may be present to limit gas loses at the inlet 31. Biomass may then exit the apparatus 10 via the last stage in the sequence, namely drying stage 20C in the variant of Fig. 1.

[0048] The pneumatic drying circuit 30 may be described as being an air conveyor extending directly from the drying gas source 31 to the inlet of the cyclonic bed reactors 21, with the stages 20A, 20B, 20C, 20n, being in parallel relative to the drying gas source 31. More particularly, the arrangement between the drying gas source 31 and the stages 20A, 20B, 20C, 20n may be said to be parallel in that drying gases from the drying gas source 31 are sent to each of the stages 20A, 20B, 20C, 20n, without having had to circulate through an upstream one of the drying stages 20.

[0049] However, with respect to the flow of biomass, the stages 20A, 20B, 20C, 20n are in series, relative to one another. The biomass flows to the drying stages 20A, 20B, 20C, 20n sequentially, as entrained by a flow of drying gases (e.g., flue gases or heat exchanger hot air stream from the torrefaction process). As the biomass is conveyed by drying gases from the pneumatic drying circuit 30, some of the drying gases may exit one stage 20 to go to another stage 20. However, by the presence of valves 22B, 23A, or other segmenting and/or sealing devices, the volume of such drying gases is relatively small in comparison to the parallel gas flow described above. The reactor chambers in the drying stage(s) 20 may therefore said be sealed.

[0050] Each segment 32 (i.e., 32A, 32B, 32C) may separate or diverge into numerous branches to supply drying gases to the cyclonic bed reactors 21 of its associated drying stage 20. This is shown in Fig. 2, as branches 32′, 32′′, 32′′′, and 32′′′′. These branches may connect with the cyclonic bed reactors 21 in any appropriate way, such as by the tangentially oriented or spiraling inlet shown. Other connection arrangements are possible. The branch arrangement shown is such that the cyclonic bed reactors 21 of a same drying stage 20 are in parallel to one another.

[0051] Still referring to Fig. 1, the pneumatic drying circuit 30 may include sustentation segments 35 including one or more blowers 36 or any appropriate type or ventilator. The blower 36 is shown as being of the type having a centrifugal fan. The sustentation segments 35 are in fluid communication with the sustentation rings 21C of the cyclonic bed reactors

21, to provide a supply of drying gases to the sustentation rings 21C. In a variant, there are as many sustentation segments 35 and associated blowers 36 as there are drying stages 20, though the blower 36 is shown as being shared by the sustentation segments 35. The blowers 36 may be optional. In Fig. 1, sustentation segment 35A is paired with drying stage 20A, sustentation segment 35B is paired with drying stage 20B, and sustentation segment 35C is paired with drying stage 20C. The blowers 36, if present, may increase gas pressure to control residence time in the cyclonic bed reactors 21. Thus, in a variant, the sustentation rings 21C are provided with combustion gases straight out of the combustor 31, i.e., not subjected to prior stages.

[0052] Referring to Figs. 1 and 2, the exhaust circuit 40 is shown as having an optional blower 41. The blowers 41 may be any appropriate type of blower or ventilator and are shown as being of the type having a centrifugal fan. Chimney 41A is present at the outlet of the blower 41. Other components may be present such as filters to scrub off airborne particles, heat exchangers (e.g., heat reclaim coils) to recuperate energy from the chimney 41A, etc. The exhaust circuit 40 may also have a manifold 42 leading to the blower 41. The manifold 42 may also having circuit segments 42A, 42B and 42C. There may be as many circuit segments 42 as there are drying stages 20. In the illustrated embodiment, circuit segment 42A is paired with drying stage 20A, circuit segment 42B is paired with drying stage 20B, and circuit segment 42C is paired with drying stage 20C. The circuit segments 42 may be connected to the top cylindrical portions 21B of the cyclonic bed reactors 21 to recuperate the combustion air having done its drying purpose. For example, as shown in Fig. 2, the circuit segments 42 may have branches 42′, 42′′, 42′′′, 42′′′ associated with respective ones of the cyclonic bed reactors 21, the branches 42′, 42′′, 42′′′, 42′′′′ converging into the manifold 42.

[0053] While the stages 20 described herein are shown as having a common pneumatic drying circuit 30 (with a common burner 31 or other drying gas source, including a hot air stream generator of any sort) and a common exhaust circuit 40, each stage 20 may have its own pneumatic drying circuit 30 and/or exhaust circuit 40. It is contemplated to recuperate heat from the exhaust circuit 40 to contribute to heating the air when supplying the drying gas. The common pneumatic drying circuit 30 may be more cost effective in terms of hardware. The common exhaust circuit 40 may be advantageous to collect particles, to recuperate energy, etc, in addition to being more cost effective.

[0054] Now that various components of the apparatus 10 have been described, an operation thereof is set forth, with reference to Figs. 1 and 2. The pneumatic drying circuit 30 operates the drying gas source 31 such that hot drying gases are blown into the manifold 32 and into the circuit segments 32A, 32B, 32C, 32n, and into the sustentation segments 35A, 35B, 35C. Biomass is fed into the inlet 33.

[0055] As drying gases flow through circuit segment 32A and pass by the inlet 33, biomass that is fed into the circuit segment 32A will be entrained by the drying gases into the drying stage 20A. There, the circuit segment 32A splits into the four branches, or into as many branches or like conduits as there are cyclonic bed reactors 21 in the drying stage 20. The biomass is therefore subjected to a cyclonic drying treatment, with the sustentation rings 21C injecting additional combustion air or dry air therein. For example, the sustentation rings 21C of the drying stage 20A receive a supply of drying gases from the sustentation segment 35A (Fig. 1). After a given residence time, the biomass is recuperated by the hopper 33, by gravity, via the appropriate sealing device, such as valve 22B. Hopper 33 of the drying stage 20A directs its biomass into the circuit segment 32B, where it will be entrained into the drying stage 20B by drying gases coming directly from the drying gas source 31 (such as from another combustor), such as one dedicated to the stage 20B).

[0056] It can be observed that the circuit segment 32B is parallel to the circuit segment 32A, in contrast to the drying stage 20A that is in series with the drying stage 20A. Therefore, the biomass that exits the drying stage 20 is exposed to a hot air stream (i.e., drying gases) from the pneumatic drying circuit 30. The biomass that is fed into the circuit segment 32B is conveyed to the drying stage 20B in which the same treatment as in the drying stage 20A will occur, though with the possibility of having a different residence time, or of being exposed to a different configuration of cyclonic bed reactor 21. However, the moisture content has been reduced by the exposure of the biomass to drying gases in the upstream drying stage 20A. At the outlet of the hopper 23 of the drying stage 20B, the biomass is received in the circuit segment 32C. Like the circuit segments 32A and 32B, the circuit segment 32C defines a flow path for drying gases that come directly out of the combustor 31 because of the parallel arrangement of the circuit segments 32A, 32B, 32C, and/or because of dedicated drying gas sources 31 (e.g., dedicated combustors). The biomass in circuit segment 32C is therefore conveyed to the drying stage 20C by drying gases, to further dry the biomass. This may be repeated with numerous drying stages. Drying stage 20C is therefore in series with drying stage 20B and therefore, the biomass has gone through sequential drying stages 20A, 20B and 20C. In the illustrated embodiment of Figs. 1 and 2, the biomass exits the system after the drying stage 20C, whereby a conveyor may be present thereat to collect the biomass.

[0057] In a variant, the drying stages 20 may be interconnected by a mechanical feeding system as an alternative to the pneumatic drying circuit 30. For example, a feedscrew unit or feedscrew conveyor may be used to move the biomass between drying stages 20.

[0058] The biomass feedstock exiting the apparatus 10 has a reduced moisture content. There may be some flash evaporation of the moisture in the biomass when it exits the apparatus 10. Depending on the desired moisture content, fewer or more of the drying stages may be present.

[0059] Gases emanating from the biomass and recuperated from the exhaust circuit 40 may be directed to the burner 31 if present, to be part of the combustion. The use of rotary valves, sas devices, etc reduce the amount of oxygen entering the system 10, or of gases exiting the apparatus 10 at locations other than at the exhaust circuit 40.

[0060] The resulting biomass may be in any appropriate format. For instance, the torrefied biomass is in a sawdust state, although it could be in flakes, granules, pellets or the like. The dried biomass may be used in any appropriate application. For example, the dried biomass may be used as a fuel in combustion, or may be processed in a torrefaction stage. Subsequent applications for torrefied biomass include non-exclusively co-firing in large coal power plants, heavy fuel oil substitution, partial substitute for coke in carbon anodes, blast furnaces, iron ore pellets, activated carbon for gas purification, gold purification, metal extraction and many other applications, soil amendment and soil remediation (mining site rehabilitation), among numerous possibilities.

[0061] In a variant, with reference to Fig. 3, the present disclosure pertains to a method 100 for drying biomass that may include steps or actions that may be described as below. According to 101, receiving biomass having a given moisture content. According to 102, directing the biomass sequentially to at least a first drying stage and then to a second drying stage, the first drying stage and the second drying stage being sealed. In one or more of the drying stages, the biomass may be divided or separated into separate streams to be fed to two or more reactors (as described above) of a same drying stage. Feeding drying gases to the drying stages may include separating the biomass in at least two biomass streams in one or more of the drying stages (though shown for all drying stages in Fig. 1. This may include exposing the biomass in the biomass streams to the flow of drying gases. The step may include receiving the biomass of the biomass streams at an exit of the drying stage(s). According to 103, drying gases (e.g., combustion gases) are fed directly from one or more burners into the first drying stage to reduce moisture content of the biomass. Alternatively, in 103, non-combustion drying gases are directed to the first drying stage. According to 104, drying gases are fed directly into the second drying stage to further reduce moisture content of the biomass. Alternatively, in 104, non-combustion drying gases are directed to the second drying stage. In the method 100, feeding combustion gases or like drying gases to the drying stages may include exposing the biomass to a flow of drying gases in a cyclonic flow. In the method 100, exposing the biomass to a cyclonic flow may include causing an annular vortex of the drying gases in the cyclonic flow to increase a residence time of the biomass in the cyclonic flow. In the method 100, feeding drying gases to the drying stages includes feeding drying gases at a temperature ranging from 150 C to 300 C. In the method 100, reducing the moisture content of the biomass may include reducing the moisture content to a range from 20% to 40%. Reducing the moisture content of the biomass may include reducing the moisture content to a range from 20% to 40% while not generating VOCs. In the method 100, directing the biomass sequentially to at least a first drying stage and then to a second drying stage may include directing the biomass using a flow of drying gases. In a variant of the method 100, feeding combustion gases directly from one or more burners into the first drying stage and into the second drying stage may include feeding the combustion gases from a common one of the one or more burners.

[0062] In another variant, the present disclosure pertains to an apparatus for drying biomass that may include: a first drying stage and at least a second drying stage configured to receive biomass and to expose the biomass to drying gases to reduce a moisture content in the biomass, the first drying stage and the second drying stage being sealed; a pneumatic drying circuit between the first drying stage and at least a second drying stage, the pneumatic drying conveyor configured to sequentially direct biomass from the first drying stage to the second drying stage using a flow of drying gases, the pneumatic drying circuit including a burner configured to produce the drying gases, the pneumatic drying circuit connecting the first drying stage and at least a second drying stage to the burner in a parallel arrangement; and an exhaust circuit in fluid communication with the first drying stage and the second drying stage for exhausting moisture from the first drying stage and the second drying stage.

[0063] While the methods and systems described herein have been described and shown with reference to particular steps performed in a particular order, it will be understood that these steps may be combined, subdivided or reordered to form an equivalent method without departing from the teachings of the present invention. Accordingly, the order and grouping of the steps is not a limitation of the present invention.

[0064] Modifications and improvements to the above-described embodiments of the present invention may become apparent to those skilled in the art. The foregoing description is intended to be exemplary rather than limiting. The scope of the present invention is therefore intended to be limited solely by the scope of the appended claims.

CLAIMS:

1. A method for drying biomass comprising:

receiving biomass having a given moisture content;

directing the biomass sequentially to at least a first drying stage and then to a second drying stage, the first drying stage and the second drying stage being sealed;

feeding drying gases directly from one or more drying gas sources into the first drying stage to reduce moisture content of the biomass; and

feeding drying gases directly from the one or more drying gas sources into the second drying stage to further reduce moisture content of the biomass.

2. The method according to claim 1, wherein feeding drying gases to the drying stages includes exposing the biomass to a flow of drying gases in a cyclonic flow.

3. The method according to claim 2, wherein exposing the biomass to a cyclonic flow includes causing an annular vortex of the drying gases in the cyclonic flow to increase a residence time of the biomass in the cyclonic flow.

4. The method according to any one of claims 1 to 3, wherein feeding drying gases to the drying stages includes feeding drying gases at a temperature ranging from 150 C to 300 C.

5. The method according to any one of claims 1 to 4, wherein reducing the moisture content of the biomass includes reducing the moisture content to a range from 20% to 40%.

6. The method according to any one of claims 1 to 5, wherein directing the biomass sequentially to at least a first drying stage and then to a second drying stage includes directing the biomass using the flow of drying gases.

7. The method according to any one of claims 1 to 6, wherein feeding drying gases includes feeding combustion gases directly from one or more burners into the first drying stage and into the second drying stage.

8. The method according to claim 7, wherein feeding combustion gases includes feeding the combustion gases from a common one of the one or more burners.

9. The method according to any one of claims 1 to 8, wherein directing the biomass sequentially to at least a first drying stage and then to a second drying stage, further includes directing the biomass to a third drying stage from the second drying stage; and feeding drying gases directly from the one or more drying gas sources into the third drying stage to further reduce moisture content of the biomass.

10. The method according to any one of claims 1 to 9, including exhausting part of the drying gases in at least the first drying stage and the second drying stage.

11. The method according to any one of claims 1 to 10, wherein feeding drying gases to the drying stages includes separating the biomass in at least two biomass streams in at least one of the drying stages, and exposing the biomass in the at least two biomass streams to the flow of drying gases.

12. The method according to claim 11, further including receiving the biomass of the at least two biomass streams in a common hopper at an exit of the drying stage.

13. An apparatus for drying biomass comprising:

a first drying stage and at least a second drying stage configured to receive biomass and to expose the biomass to drying gases to reduce a moisture content in the biomass, the first drying stage and the second drying stage being sealed;

a pneumatic drying circuit in fluid communication with the first drying stage and at least a second drying stage, the pneumatic drying circuit configured to sequentially direct biomass from the first drying stage to the second drying stage using a flow of drying gases, the pneumatic drying circuit including a drying gas source configured to provide the drying gases, the pneumatic drying circuit connecting the first drying stage and at least a second drying stage to the drying gas source in a parallel arrangement; and

an exhaust circuit in fluid communication with the first drying stage and the second drying stage for exhausting moisture from the first drying stage and the second drying stage.

14. The apparatus according to claim 13, wherein the first drying stage and the second drying stage each include at least one cyclonic bed reactor.

15. The apparatus according to claim 14, wherein the first drying stage and the second drying stage each include a plurality of the at least one cyclonic bed reactor, the

cyclonic bed reactors of the plurality being parallel to one another in the respective drying stage.

16. The apparatus according to claim 15, wherein each of the drying stages includes a common hopper downstream of the plurality of cyclonic bed reactors for collecting biomass from the plurality of cyclonic bed reactors.

17. The apparatus according to any one of claims 14 to 16, wherein the cyclonic bed reactors have valves at a biomass outlet and at a connection with the exhaust circuit.

18. The apparatus according to any one of claims 13 to 17, wherein the pneumatic drying circuit includes a circuit portion being connected to the drying stages in parallel and configured for directly feeding drying gas to the drying stages.

19. The apparatus according to any one of claims 13 to 18, including at least a third drying stage configured to receive biomass and to expose the biomass to drying gases to reduce the moisture content in the biomass, and wherein the pneumatic drying circuit is in fluid communication with third drying stage, the pneumatic drying circuit configured to sequentially direct biomass from the second drying stage to the third drying stage using the flow of drying gases.

20. The apparatus according to any one of claims 13 to 19, wherein the drying gas source is one or more burners, and the drying gas includes combustion gases.

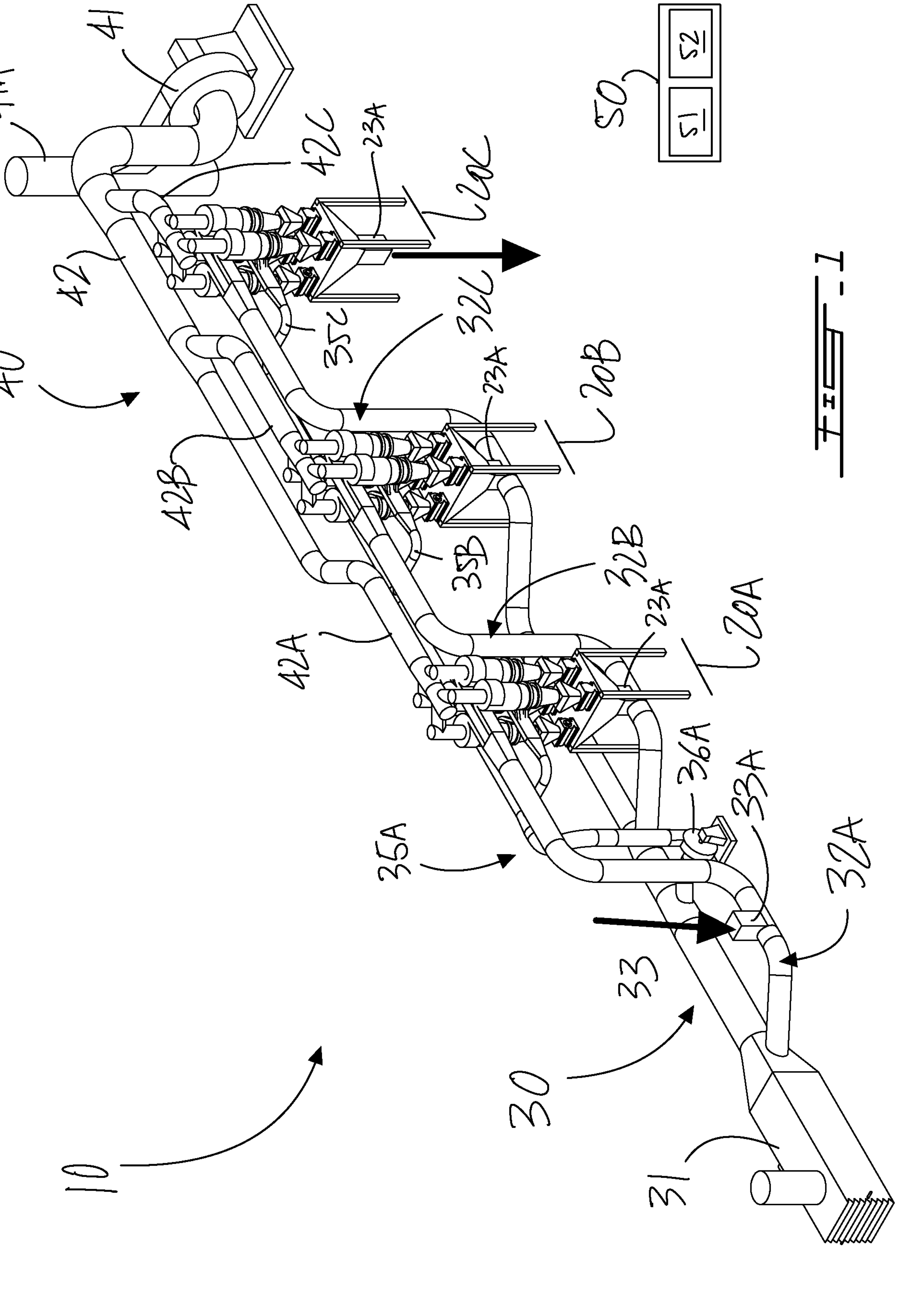
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FIG. 1

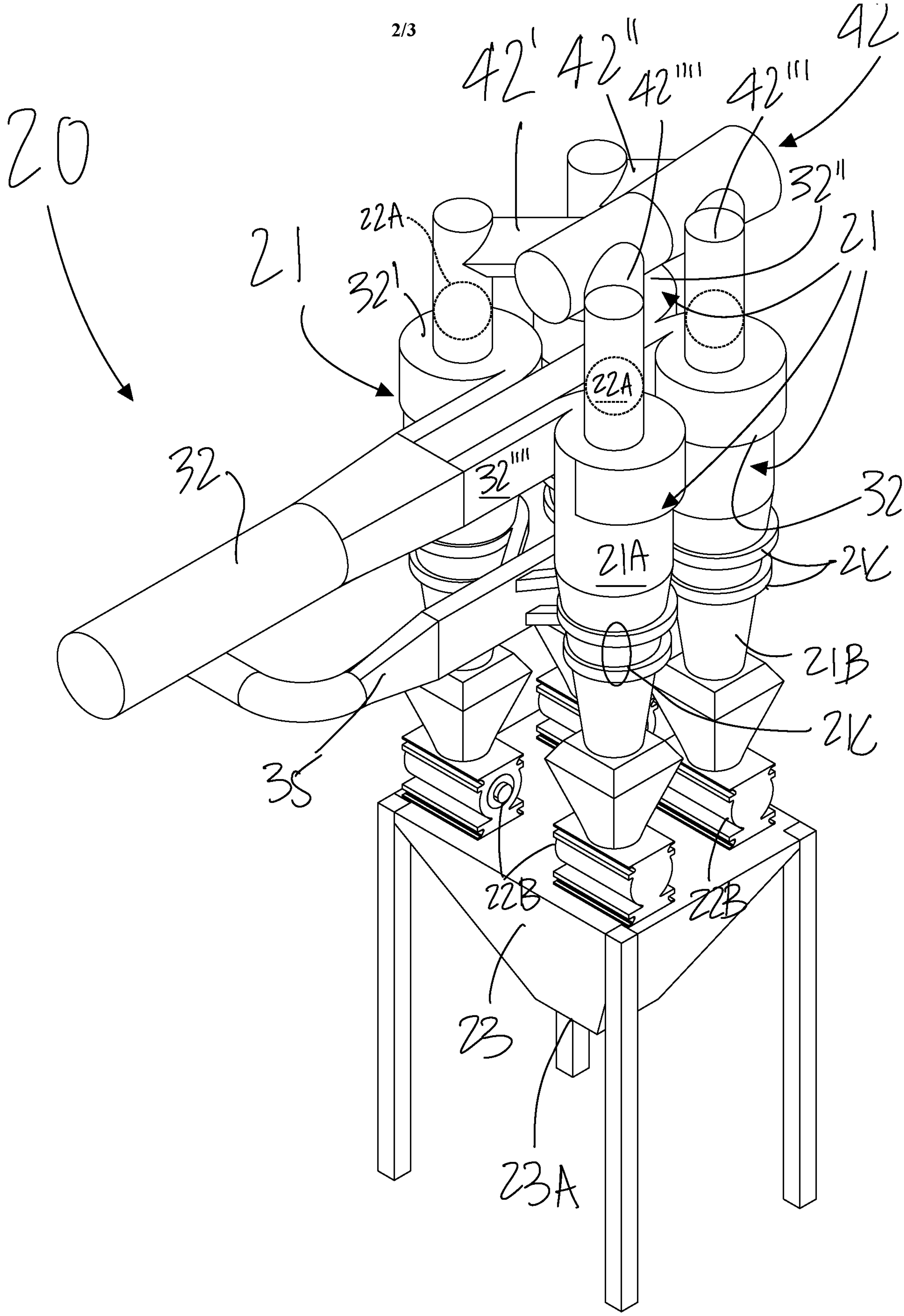
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FIG. 2

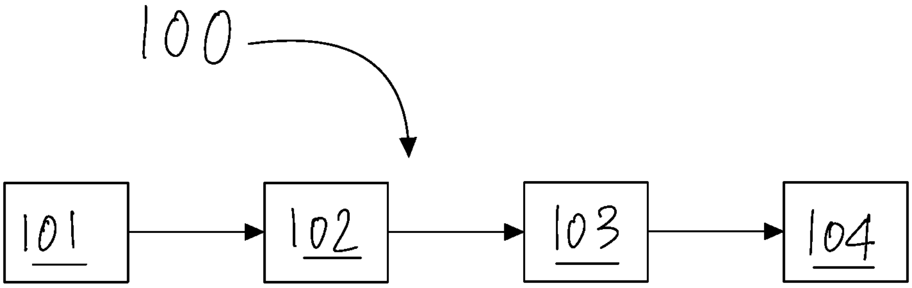

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2024/050760

A. CLASSIFICATION OF SUBJECT MATTER

IPC: ***C10L 9/08*** (2006.01), ***F26B 3/10*** (2006.01), ***F26B 17/10*** (2006.01)

CPC: **C10L 9/083** (2020.01), C10L2290/08 (2020.01), C10L2290/52 (2020.01), C10L2290/56 (2020.01), F26B 3/10 (2020.01), F26B 17/107 (2020.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C10L 9/08 (2006.01), ***F26B 3/10*** (2006.01), ***F26B 17/10*** (2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Orbit (cyclonic bed reactor, torrefaction reactor, biomass, drying, cyclonic, gas, stage)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 102589254 A (BIE, R. et al.) 2012 July 18 (2012-07-18) * whole document * * machine translation provided by Orbit used for understanding *	1-20

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"D"	document cited by the applicant in the international application	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"E"	earlier application or patent but published on or after the international filing date	"&"	document member of the same patent family
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)		
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search	Date of mailing of the international search report
20 August 2024 (20-08-2024)	20 August 2024 (20-08-2024)

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Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
CN102589254A	18 July 2012 (18-07-2012)	None	