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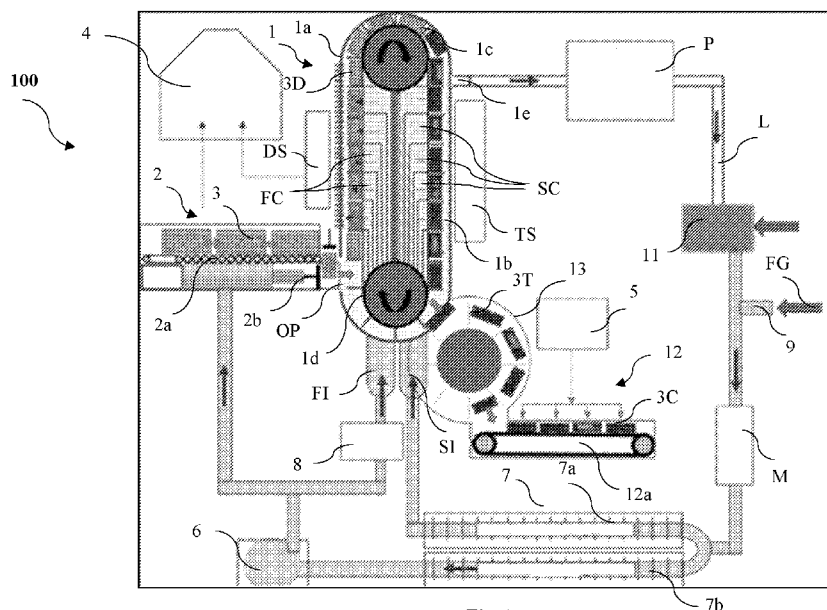


Fig. 1

(57) Abstract: Present disclosure discloses a system (100) and a method for processing biomass. The system comprises a reaction chamber (1) including a first chamber (1a) adapted to receive biomass bales from a loading station (2). The first chamber is configured to dry each of the plurality biomass bales by passage of a flue gas (FG) into the first chamber at a first predetermined temperature range and a first predetermined flue gas flux range. Further, a second chamber (1b) located adjacent to the first chamber receives biomass bales from the first chamber. Each biomass bale undergoes torrefaction at the second chamber by passage of the flue gas into the second chamber at a second predetermined temperature range and a second predetermined flue gas flux range. The system (100) eliminates need for preprocessing of biomass and provides a cost-effective solution for torrefaction of biomass in a single, compact vertical reaction chamber (1).

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“A SYSTEM FOR PROCESSING BIOMASS AND A METHOD THEREOF”**TECHNICAL FIELD**

5 [001] Present disclosure generally relates to processing of biomass. Particularly, but not exclusively, the present disclosure relates to drying and torrefaction of bales of biomass. Further, embodiments of the disclosure disclose a system and a method for drying and torrefaction of the biomass bales in a single reaction chamber.

10 **BACKGROUND OF THE DISCLOSURE**

[002] Agriculture is a major industrial sector for any country. Farmers indulged in agriculture produce tons of harvest of various edible and non-edible perishable stuffs such as rice, wheat, corn, rubber, cereals, wood etc. In a country like India, agriculture is part and parcel of more than half the population and is regarded as the backbone of country's progress, especially the economy. Primarily, such a large industry, even though produces lots of food stuffs, a lot of residues is also left over. For example, growing of rice and wheat needs a lot of processing post harvesting. During this period a lot of residues such as paddy straw or wheat straw is left over. Such residues are usually burnt in open air. Conventionally, burning of such residue leads to a lot of smoke and creates smog in the atmosphere leading to a poor air quality index [AQI]. Moreover, some farmers have no idea about pre-processing such residue and follow age old traditions and simply burn such residues without giving heed to the damages that may cause the environment. In some cases, even though there are entities for processing of such agricultural residues, the costs and time involved in processing or pre-processing such residues are extremely high and not feasible. However, if appropriately conditioned to be used as a source of energy, paddy straw or wheat straw may serve as biofuels and may manifest as an important energy source. Country like India generates about 170 million tons of straw per annum from paddy alone and almost all of it is generally burned in fields (as Paddy straw is not a very good source of nutrition for cattle/bovine).

30 [003] Instead of burning the straw and similar biomass in open spaces leading to atmospheric pollution, they may be diverted into processing facilities to undergo torrefaction process (a thermochemical process resulting in a solid product having improved energy density and several chemical and physical properties). By subjecting to torrefaction, a typical yield of about 120

million tons of torrefied product per annum may be attained. This is beneficial in replacing around 11% of fossilized coal to meet the energy demands. Such a replacement has multiple benefits for India where majority of energy demand is met by burning coal in power plants. It is not only environmentally benign considering that the torrefied straw qualifies as a “green fuel”, but is also helpful from the perspective that the residual straw is no longer accumulated or burned in the open atmosphere. Such a replacement will assist in meeting the CoP-15 commitments while enhancing national energy security.

[004] From the perspective of using straw for energy needs, currently, paddy and wheat straw bales are further processed to generate small size dry briquettes to be used in downstream thermal applications. In the briquetting process, the given bales are first cut and then dried to drive away the moisture, after which they may be transformed into a powdered form by processes such as hammering. This powder is conveyed to the compressor, where the pellets/ briquettes are made. It is important to note that briquetting paddy or wheat straw is a challenging process considering the nature of the feed. A briquetting machine generating about 30 ton/day of briquettes using mustard or cotton straw can only generate about 12 ton/day briquettes using paddy/wheat straw as the raw material. The reduction in the capacity is due to factors like choking of the conveyor pulley, restricted movement of the paddy straw powder in the screw conveyor and so on. Similarly, pulverizing the straw, especially the paddy straw is also challenging and is a highly energy intensive process. Torrefaction of straw can substantially reduce the associated challenges and reduce the energy inputs by making the downstream processing, such as briquetting, pelletizing or pulverizing significantly simple.

[005] Present disclosure is directed to overcome one or more limitations stated above or any other limitation associated with the existing biomass processing techniques and systems.

SUMMARY OF THE DISCLOSURE

[006] One or more shortcomings of the prior arts are overcome by the system and the method as disclosed in the present disclosure and additional advantages are provided through the system and the method. Additional features and advantages are realized through the techniques of the present

disclosure. Other embodiments and aspects of the disclosure are described in detail herein and are considered a part of the claimed disclosure.

[007] In a non-limiting embodiment of the present disclosure, a system for processing biomass is disclosed. The system comprises a reaction chamber including a first chamber adapted to receive a plurality of biomass bales from a loading station. The first chamber is configured to dry each of the plurality biomass bales by passage of a flue gas into the first chamber at a first predetermined temperature range and a first predetermined flue gas flux range. Further, the reaction chamber includes a second chamber located adjacent to the first chamber, the second chamber is adapted to receive the plurality of biomass bales from the first chamber. Each of the plurality of biomass bales undergoes torrefaction at the second chamber by passage of the flue gas into the second chamber at a second predetermined temperature range and a second predetermined flue gas flux range. A first conveyer bridges the first chamber and the second chamber, and is configured to transport the plurality of biomass bales from the first chamber to the second chamber.

[008] In an embodiment of the present disclosure, the loading station comprises a second conveyer including a plurality of provisions, each provision structured to support and transport one of the plurality of biomass bales. Further, at least one plunger is disposed proximal to an opening defined in the first chamber, the at least one plunger is configured to assist in loading each of the plurality of biomass bales into the first chamber through the opening.

[009] In an embodiment of the present disclosure, the second chamber comprises an outlet defined at a top portion to purge products of torrefaction from the second chamber.

[0010] In an embodiment of the present disclosure, the system comprises a flue gas supply fluidly disposed downstream of the outlet. The flue gas supply is configured to supply the flue gas to the first chamber for drying the plurality of biomass bales, and the second chamber for the torrefaction of the plurality of biomass bales.

[0011] In an embodiment of the present disclosure, the system comprises a plurality of first channels defined in the first chamber. The plurality of first channels are fluidly coupled to the flue gas supply, and configured to channelize the flue gas at the first predetermined flue gas flux range

into the first chamber. Further, the system comprises a plurality of second channels defined in the second chamber. The plurality of second channels are fluidly coupled to the flue gas supply, and configured to channelize the flue gas at the second predetermined flue gas flux range into the second chamber.

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[0012] In an embodiment of the present disclosure, the system comprises at least one flow control valve configured to regulate flow of the flue gas into the first chamber and the second chamber.

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[0013] In an embodiment of the present disclosure, the system comprises a heat exchanging unit coupled between the flue gas supply and the second chamber. The heat exchanging unit is configured to regulate temperature of the flue gas supplied to the second chamber for the torrefaction of the plurality of biomass bales. Further, the system comprises a flow creation device configured to distribute the flue gas between the loading station and the first chamber.

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[0014] In an embodiment of the present disclosure, the system comprises a dilution air device fluidly disposed between the first chamber and the flow creation device. The dilution air device is configured to discharge diluted air into the flue gas flowing into the first chamber.

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[0015] In an embodiment of the present disclosure, the system comprises a cooling station adapted to receive plurality of torrefacted biomass bales from the second chamber for cooling the plurality of torrefacted biomass bales to a predetermined temperature. The cooling station includes a third conveyer configured to transport the plurality of torrefacted biomass bales in heat exchanging communication with at least one coolant. Further, a transfer unit is disposed between the cooling station and the second chamber. The transfer unit is configured to provide an inert atmosphere for transfer of the plurality of torrefacted biomass bales from the second chamber to the cooling station.

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[0016] In an embodiment of the present disclosure, the first predetermined temperature for drying the plurality of biomass bales ranges from 100 °C to 175 °C, and the second predetermined temperature for torrefacting the plurality of biomass bales ranges from 250 °C to 350 °C.

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[0017] In an embodiment of the present disclosure, the first predetermined flue gas flux for drying the plurality of biomass bales (3) ranges from 150 ± 25 gm/m²-sec to 100 ± 25 gm/m²-sec, and the second predetermined flue gas flux for torrefacting the plurality of biomass bales (3) ranges from 275 ± 25 gm/m²-sec to 200 ± 25 gm/m²-sec.

5 [0018] In another non-limiting embodiment of the present disclosure, a method for processing biomass is disclosed. The method includes receiving, by a first chamber defined in a reaction chamber, a plurality of biomass bales from a loading station. Then, the method includes drying, in the first chamber, the plurality of biomass bales at a first predetermined temperature range and a first predetermined flue gas flux range by passage of flue gas into the first chamber. Further, the
10 method includes transporting, by a first conveyer, the plurality of biomass bales from the first chamber to a second chamber located adjacent to the first chamber, where the first conveyer bridges the first chamber and the second chamber. The method then includes torrefacting, in the second chamber, the plurality of biomass bales at a second predetermined temperature and a second predetermined flue gas flux range, by passage of the flue gas into the second chamber.

15 [0019] In an embodiment of the present disclosure, the method comprises removing moisture containing gases from the first chamber through an exhaust hood after drying the plurality of biomass bales at the first predetermined temperature.

20 [0020] In an embodiment of the present disclosure, the method comprises supplying, by a flue gas supply, the flue gas to the first chamber for drying the plurality of biomass bales, and the second chamber for the torrefaction of the plurality of biomass bales.

[0021] In an embodiment of the present disclosure, the method comprises distributing the flue gas
25 to the first chamber and the loading station by a flow creation device, wherein the flow creation device is fluidly disposed between the loading station and the first chamber.

[0022] In an embodiment of the present disclosure, the method comprises discharging diluted air
30 into the flue gas by a dilution air device, wherein the dilution air device is fluidly disposed between the first chamber and the flow creation device. Further, the comprises regulating temperature of

the flue gas supplied to the second chamber by a heat exchanging unit, wherein the heat exchanging unit is coupled between the flue gas supply and the second chamber.

[0023] In an embodiment of the present disclosure, the method comprises regulating, by at least one flow control valve, flow of the flue gas into the first chamber and the second chamber.

[0024] In an embodiment of the present disclosure, the method comprises combusting products of the torrefaction by a combustion device disposed downstream of the second chamber.

[0025] In an embodiment of the present disclosure, the method comprises cooling each of plurality of torrefacted biomass bales exiting from the second chamber at a cooling station. The cooling station includes a third conveyer configured to transport the plurality of torrefacted biomass bales in heat exchange communication with at least one coolant.

[0026] It is to be understood that the aspects and embodiments of the disclosure described above may be used in any combination with each other. Several of the aspects and embodiments may be combined together to form a further embodiment of the disclosure.

[0027] The foregoing summary is illustrative only and is not intended to be in any way limiting.

In addition to the illustrative aspects, embodiments, and features described above, further aspects, embodiments, and features will become apparent by reference to the drawings and the following detailed description.

BRIEF DESCRIPTION OF THE ACCOMPANYING FIGURES

[0028] The novel features and characteristics of the disclosure are set forth in the appended description. The disclosure itself, however, as well as a preferred mode of use, further objectives, and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying figures. One or more embodiments are now described, by way of example only, with reference to the accompanying figures wherein like reference numerals represent like elements and in which:

[0029] Fig. 1 illustrates a schematic of a system for processing biomass, according to some embodiments of the present disclosure;

[0030] Fig. 2 is a schematic illustrating the process flow involved in processing the biomass using the system of Fig. 1;

[0031] Fig. 3 illustrates a schematic of an experimental set-up for torrefaction of straw samples using engine exhaust as an energy source, according to an embodiment of the present disclosure; and

[0032] Figs. 4A and 4B are graph illustrations of Temperature-Time plot of the biomass bed with a maximum temperature of 250 °C and 280 °C, respectively, according to an embodiment of the present disclosure.

[0033] The figures depict embodiments of the disclosure for purposes of illustration only. One skilled in the art will readily recognize from the following description that alternative embodiments of the methods illustrated herein may be employed without departing from the principles of the disclosure described herein.

DETAILED DESCRIPTION

[0034] The foregoing has broadly outlined the features and technical advantages of the present disclosure in order that the detailed description of the disclosure that follows may be better understood. Additional features and advantages of the disclosure will be described hereinafter which form the subject of the description of the disclosure. It should also be realized by those skilled in the art that such equivalent methods do not depart from the scope of the disclosure. The novel features which are believed to be characteristics of the disclosure, as to method of operation, together with further objects and advantages will be better understood from the following description when considered in connection with the accompanying figures. It is to be expressly understood, however, that each of the figures is provided for the purpose of illustration and description only and is not intended as a definition of the limits of the present disclosure.

[0035] In the present document, the word "exemplary" is used herein to mean "serving as an example, instance, or illustration." Any embodiment or implementation of the present subject

matter described herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments.

[0036] While the disclosure is susceptible to various modifications and alternative forms, specific
5 embodiments thereof have been shown by way of example in the drawings and will be described in detail below. It should be understood, however that it is not intended to limit the disclosure to the particular forms disclosed, but on the contrary, the disclosure is to cover all modifications, equivalents, and alternative falling within the scope of the disclosure.

10 [0037] The terms "comprises", "comprising", or any other variations thereof, are intended to cover non-exclusive inclusions, such that a method or a system that comprises a list of acts does not include only those acts but may include other acts not expressly listed or inherent to such a method or a system. In other words, one or more acts in a method preceded by "comprises... a" does not, without more constraints, preclude the existence of other acts or additional acts in the method or
15 the system.

[0038] Embodiments of the present disclosure disclose a system for processing biomass. The system comprises a reaction chamber including a first chamber adapted to receive a plurality of biomass bales from a loading station. The first chamber is configured to dry each of the plurality
20 biomass bales by passage of a flue gas into the first chamber at a first predetermined temperature range and a first predetermined flue gas flux range. Further, the reaction chamber includes a second chamber located adjacent to the first chamber, the second chamber is adapted to receive the plurality of biomass bales from the first chamber. Each of the plurality of biomass bales undergoes torrefaction at the second chamber by passage of the flue gas into the second chamber at a second
25 predetermined temperature range and a second predetermined flue gas flux range. In an embodiment of the present disclosure, the first predetermined temperature for drying the plurality of biomass bales may range from 100 °C to 175 °C, and the second predetermined temperature for torrefacting the plurality of biomass bales may range from 250 °C to 350 °C. In an embodiment of the present disclosure, the first predetermined flue gas flux for drying the plurality of biomass
30 bales (3) ranges from 150+/-25 gm/m²-sec to 100+/-25 gm/m²-sec, and the second predetermined flue gas flux for torrefacting the plurality of biomass bales (3) ranges from 275+/-25 gm/m²-sec to

200+/-25 gm/m²-sec. A first conveyer may bridge the first chamber and the second chamber, and may transport the plurality of biomass bales from the first chamber to the second chamber. In an embodiment, the loading station present in the system may include a second conveyer including a plurality of provisions, each provision structured to support and transport a biomass bale. Further, at least one plunger forming a part of the loading station may be disposed proximal to an opening defined in the first chamber. The at least one plunger is configured to assist in loading each of the plurality of biomass bales into the first chamber through the opening. In an embodiment, the at least one plunger may also take part in compacting and/or resizing each of the plurality of biomass bales.

[0039] Torrefaction is a thermochemical process where organic matter containing carbonaceous substances, such as hydrocarbons, are subjected to undergo chemical changes at elevated temperatures, for example, temperatures ranging from 200 °C – 300 °C or much higher temperature values. Torrefaction is usually performed under inert conditions which eventually results in formation of a solid product having improved energy density and physical properties (including, but not limited to hydrophobicity, grindability, pellet ability, sphericity and specific surface area). Torrefaction process, besides leading to the formation of solid product(s), may also release condensable and non-condensable gases including tars, CO, CO₂, H₂, CH₄ and C₂H₄. Therefore, torrefaction is highly sensitive to the quality (temperature) and quantity (mass flux or mass flow rate per unit area of cross section) of the gases used for torrefaction. The relative yields of liquid fractions along with higher molecular weight fractions during torrefaction are a strong function of temperature and residence time. Torrefaction is highly sensitive to the quality (temperature) and quantity (mass flux) of the gases used for torrefaction and as such, controlled experiments are critical to establish the requirement.

[0040] Further, the second chamber present in the reaction chamber may have an outlet defined at a top portion to purge products of torrefaction from the second chamber. The purged products moving out through the outlet may flow through a downstream pipe having a flue gas supply which is fluidly disposed downstream of the outlet. The flue gas supply is configured to deliver the flue gas to the first chamber for drying the plurality of biomass bales, and the second chamber for the torrefaction of the plurality of biomass bales. In an embodiment, the flue gas may be supplied from

sources including, but not limited to direct combustion of LPG/CNG/PNG in a combustion engine, a gasification system, a torrefied product burner or a power plant exhaust. To transport or carry the flue gases from the flue gas supply into the reaction chamber, the first chamber may be defined with a plurality of first channels. The plurality of first channels may be fluidly coupled to the flue gas supply, and configured to channelize the flue gas at the first predetermined flue gas flux range into the first chamber. Similarly, the second chamber may include a plurality of second channels, each fluidly coupled to the flue gas supply, and configured to channelize the flue gas at the second predetermined flue gas flux range into the second chamber. At least one flow control valve may be provided upstream of to regulate flow of the flue gas into the first chamber and the second chamber. The system may also include a heat exchanging unit coupled between the flue gas supply and the second chamber. The heat exchanging unit may be intended to regulate temperature of the flue gas supplied to the second chamber for the torrefaction of the plurality of biomass bales. In an embodiment, the heat exchanger may be a non-contact type heat exchanger. In addition to heat exchanger, the system may include a flow creation device which may take part in distribution of the flue gas between the loading station and the first chamber. In an embodiment, the flue gas discharged to the loading station by the flow creation device may perform preliminary drying of the biomass bales during travel inside the loading station towards the first chamber. Further, a dilution air device may be fluidly disposed between the first chamber and the flow creation device to discharge and mix diluted air into the flue gas flowing into the first chamber. In an embodiment, the diluted air discharged into the flue gas may reduce the temperature of the flue gas to desired magnitudes adequate for drying the biomass bales.

[0041] In an embodiment of the present disclosure, the system may include a cooling station adapted to receive plurality of torrefacted biomass bales from the second chamber for cooling the plurality of torrefacted biomass bales to a predetermined temperature. The cooling station may have a third conveyer which transports the plurality of torrefacted biomass bales in heat exchanging communication with at least one coolant. Further, a transfer unit may be disposed between the cooling station and the second chamber. The transfer unit is intended to provide an inert atmosphere during transfer of the plurality of torrefacted biomass bales from the second chamber to the cooling station.

[0042] The present disclosure also discloses a method for processing biomass. The method includes receiving, by a first chamber defined in a reaction chamber, a plurality of biomass bales from a loading station. Then, the method includes drying, in the first chamber, the plurality of biomass bales at a first predetermined temperature range and a first predetermined flue gas flux range by passage of flue gas into the first chamber. Further, the method includes transporting, by a first conveyer, the plurality of biomass bales from the first chamber to a second chamber located adjacent to the first chamber, where the first conveyer bridges the first chamber and the second chamber. The method then includes torrefacting the biomass bales, in the second chamber, at a second predetermined temperature and a second predetermined flue gas flux range, by passage of the flue gas into the second chamber. In an embodiment, the method includes removing moisture containing gases from the first chamber through an exhaust hood after drying the plurality of biomass bales at the first predetermined temperature.

[0043] The present disclosure is explained with the help of figures. However, such exemplary embodiments should not be construed as limitations of the present disclosure since the method disclosed may be used or employed for any manufacturing process. A person skilled in the art may envisage various such embodiments without deviating from scope of the present disclosure.

[0044] Fig. 1 illustrates an exemplary system (100) for processing biomass. Particularly, present disclosure describes a system (100) which processes biomass through drying and torrefaction steps performed in a single reaction chamber (1).

[0045] The system (100) disclosed in embodiments of the present disclosure employs a single reaction chamber (1) as shown in Fig. 1. The system (100) is configured in such a way that the reaction chamber (1) may receive and process the biomass in raw or crude form, without the need of any pre-processing or preparation of the biomass. For example, in a typical briquetting process, the biomass may be stacked into rectangular form or rolled into cylindrical form to generate small sized briquettes. However, before the briquetting process, the bales [alternately referred to as “bale loves” through the description] are cut and dried to drive away moisture by any of the known drying methods. This is followed by hammering the dried bales to transform them into powdered

form which may be then fed to press where briquettes are made. The system (100) of the present disclosure is intended to eliminate the need for such time consuming and tedious pre-processing/preparation steps.

5 [0046] The reaction chamber (1), as shown, may preferably be in the form of a vertical tower, although other generic shapes which serve the purpose of torrefaction and drying may be employed. The reaction chamber (1) may be divided into two separate chambers adjacently located to each other i.e., a first chamber (1a) which may receive the biomass bales in crude [raw or unprocessed form] where drying of the bales/loves takes place, and a second chamber (1b) which
10 may take part in the torrefaction. The first chamber (1a) may include an opening (OP) defined at a predetermined location to receive a plurality of biomass bales (3). In an embodiment, the first chamber (1) may receive the plurality of biomass bales (3) through the opening (OP) from a loading station (2), as shown in Fig. 1. The loading station (2) includes a second conveyer (2a) having a plurality of provisions [not shown], each provision structured to support and transport a
15 biomass bales (3) towards the first chamber (1a).

[0047] In an embodiment, at least one plunger (2b) may be provided inside the loading station (2) such that the at least one plunger (2b) may be disposed proximal to the opening (OP) defined in the first chamber (1a). The at least one plunger (2b) may assist in loading each of the plurality of
20 biomass bales (3) into the first chamber (1a) through the opening (OP). In another embodiment, the at least one plunger (2b) may also take part in compacting and/or resizing each of the plurality of biomass bales (3) besides assisting in loading into the first chamber (1a). In an embodiment, the at least one plunger (2b) may be operated by electric, hydraulic, pneumatic power. Further, the second conveyer (2a) may be a horizontal slot conveyer or a mesh conveyer, however, the same
25 shall not be considered as a limitation as any other type of conveyor system suitable for such requirement may be employed.

[0048] The reaction chamber (1) containing the first chamber (1a) and the second chamber (1b) may contain a first conveyer (1d) to bridge the first chamber (1a) and the second chamber (1b).
30 The first conveyer (1d), as shown, may be a vertical conveyer running seamlessly between the first chamber (1a) and the second chamber (1b), and may transport the plurality of biomass bales from

the first chamber (1a) to the second chamber (1b). In an embodiment, the first conveyer (1d), like the second conveyer, may be a slot conveyer or a mesh conveyer, but running in a vertical direction. The first conveyer (1d) may also contain carefully designed provisions [not shown] which may adeptly support and carry the biomass bales (3) in the vertical direction between the first chamber (1a) and the second chamber (1b). The first chamber (1a) may be configured to dry the plurality of biomass bales (3) using flue gas (FG) received from a flue gas supply (9), as shown. In an embodiment of the disclosure, the first chamber (1a) may be defined with a plurality of first channels (FC) to transport or direct the flue gas (FG) from the flue gas supply (9) into the first chamber (1a). The plurality of first channels (FC) may be fluidly coupled to the flue gas supply (9), and configured to channelize the flue gas (FG) at a first predetermined flue gas flux range [flue gas flow rate per unit area of cross section] and at a first predetermined temperature range into the first chamber (1a). In an embodiment, the flue gas (FG) may enter from a first inlet (FI) into the first chamber (1a), and the moisture laden gases exit from other side (DS) of the first chamber (1a) through an exhaust hood (4) after drying the plurality of biomass bales (3). In another embodiment, the plurality of first channels (FC) may provide necessary support to the biomass bales (3) and prevent the biomass bales from falling off while moving in the first conveyer (1d). In an embodiment, the flue gas (FG) may be a single gaseous component or a mixture of several gases, for example, a mixture of gases coming out of an engine exhaust.

[0049] In an embodiment, each of the first channels (FC) may have a separate flue gas (FG) feed system with a provision for temperature and mass flux control. For instance, each of the first channels may have a different cross-sectional area in comparison to an adjacent first channel, so that mass flux of the flue gas (FG) through each of the first channels is different. In an embodiment, the cross-sectional area of the first channel (FC) may gradually increase in upward direction with lowermost first channel having least cross-sectional area, and uppermost first channel having highest cross-sectional area. In an alternate embodiment, each of the first channels (FC) may be provided with a valve, for example, a flow control valve to regulate mass flux of the flue gas (FG) through each of the first channels (FC). Regulation of temperature and flux of the flue gas (FG) will ensure effective utilization of energy for sensible heating and moisture extraction process.

[0050] Further, factors such as speed of the first conveyor (1d), first predetermined flue gas flux range and the first predetermined temperature range of the flue gas (FG) in the first chamber (1a) may be regulated in such a way that the moisture from the biomass bales (3) may be removed by the time the biomass bales (3) reach the top of the first chamber (1a). In an embodiment, the first predetermined flue gas flux is the drying gas flux accompanied by residence time of biomass bales inside the first chamber (1a). In an embodiment, the first predetermined temperature ranges from 100 °C to 175 °C, depending on the type of biomass under consideration. For instance, in case of paddy straws, the first predetermined temperature at which drying takes place may vary between 150 °C and 175 °C, with paddy straws reaching temperature as high as 175 °C at the top of the first chamber (1a) to release moisture. In another embodiment of the present disclosure, the first predetermined flue gas flux for drying the plurality of biomass bales (3) ranges from 150+/-25 gm/m²-sec to 100+/-25 gm/m²-sec. For instance, if the first predetermined temperature range is maintained at 100 °C – 110 °C, then the first predetermined flue gas flux may be maintained in range of 150+/-25 gm/m²-sec to perform moisture extraction from the biomass bales (3) in the first chamber (1a). Similarly, if a higher first predetermined temperature range is maintained, say 160 °C to about 175 °C, then a lesser first predetermined flue gas flux may be employed, for example, in the range of 100+/-25 gm/m²-sec to perform moisture extraction from the biomass bales (3) in the first chamber (1a).

[0051] The flue gas (1a) entering from the first inlet (FI) may fill the first chamber (1a) and may pass through each biomass bale (3) to extract or pick-up the moisture present in each biomass bale (3). The flue gas (3) entering at the first predetermined temperature range may also heat the biomass bales (3) while it removes moisture, thereby resulting in reduction of weight of each biomass bale (3) by about 20%. The system (100) as shown in Fig. 1 may include a flow creation device (6) which may take part in distribution of the flue gas between the loading station (2) and the first chamber (1a). The flow creation device (6), as shown, may be fluidly coupled to the flue gas supply (9) to form a closed circuit with respect to the reaction chamber (1). In an embodiment, the flow creation device (6) may be a pump, a blower, a fan or any other fluid-based device which serves the purpose of distributing the flue gas (FG) between the loading station (2) and the first chamber (1a). In an embodiment, the flue gas (FG) discharged to the loading station (2) by the flow creation device (6) may perform preheating and preliminary drying of the raw or crude biomass bales (3)

loaded into the loading station (2). In an embodiment, preheating and preliminary drying inside the loading station (3) may take place at a temperature range of 65 °C and 75 °C. Since the temperature of the flue gas (FG) entering the flow creation device (6) is relatively high, a dilution air device (8) may be fluidly disposed between the flow creation device (6) and the first chamber (1a) [as shown in Fig. 1] and optionally between the flow creation device (6) and the loading station (2). In an embodiment, the dilution air device (8) may be a fan, a compressor, a pump or a blower which discharges diluted air into the stream of incoming flue gas (FG). The objective of discharging diluted air is to lessen the temperature of the flue gas (FG) to levels suitable for drying the biomass bales (3) at the loading station (2) as well as the first chamber (3).

[0052] Once the drying step is complete, the dried biomass bales (3D) may be conveyed or transferred via transition section (1c) into the second chamber (1b). The transition section (1c) may define the topmost portion of the reaction chamber (1) which may interlink the first chamber (1a) and the second chamber (1b). The second chamber (1b), which may also be referred to as torrefaction chamber, is a mirror image of the first chamber (1a) with the only difference being the movement of dried biomass bales (3D) taking place in the downward direction. Each of the dried biomass bales (3D) entering the second chamber (1b) undergoes torrefaction in the presence of the flue gas (FG) discharged into the second chamber (1b) at a second predetermined temperature range and a second predetermined flue gas flux range. As shown in Fig. 1, the flue gas (FG) from the flue gas supply (9) may be let into the second chamber (1b) via the second inlet (SI). In an embodiment of the present disclosure, the second predetermined temperature for torrefacting the plurality of dried biomass bales (3) may range from 250 °C to 350 °C. For instance, in case of paddy straws, the second predetermined temperature range at which torrefaction takes place may vary between 250 °C and 275 °C, with paddy straws reaching temperature as high as 275 °C as they passes downwardly through the second chamber (1b) to undergo torrefaction. In another embodiment of the present disclosure, the second predetermined flue gas flux for drying the plurality of biomass bales (3) ranges from 275+/-25 gm/m²-sec to 200+/-25 gm/m²-sec. For instance, if the second predetermined temperature range is maintained at 250 °C - 270 °C, then the second predetermined flue gas flux may be maintained around 275+/-25 gm/m²-sec to perform torrefaction of the biomass bales (3) in the second chamber (1b). Similarly, if a higher second predetermined temperature range is maintained, say 340 °C to about 350 °C, then a lesser second

predetermined flue gas flux may be employed, for example, in the range of 200 ± 25 gm/m²-sec, to perform torrefaction of the biomass bales (3) in the second chamber (1b).

[0053] In an embodiment of the disclosure, the second chamber (1b) may be defined with a plurality of second channels (SC) to transport or carry the flue gas (FG) from the flue gas supply (9) into the first chamber (1a). The plurality of second channels (SC) may be fluidly coupled to the flue gas supply (9), and may channelize the flue gas (FG) at the second predetermined flue gas flux range [flue gas flow rate per unit area of cross section] and at the second predetermined temperature range into the second chamber (1b). In an embodiment, the second predetermined flue gas flux is the pyrolyzing gas flux accompanied by residence time of biomass bales inside the second chamber (1b).

[0054] In an embodiment, each of the second channels (SC) may have a separate flue gas (FG) feed system with a provision for temperature and mass flux control. For instance, each of the second channels (SC) may have a different cross-sectional area in comparison to an adjacent second channel, so that mass flux of the flue gas (FG) through each of the second channels is different. In an embodiment, the cross-sectional area of the second channel (SC) may gradually increase in downward direction with uppermost second channel having least cross-sectional area, and lowermost second channel having highest cross-sectional area. In an alternate embodiment, each of the second channels (SC) may be provided with a valve, for example, a flow control valve to regulate mass flux of the flue gas (FG) through each of the second channels (SC). Regulation of temperature and flux of the flue gas (FG) will ensure effective utilization of energy for sensible heating and torrefaction process. The biomass bales (3) when exposed to the flue gas (FG) in the second chamber (1b) undergo torrefaction which is accompanied by changes in chemical and physical changes at elevated temperatures. Torrefaction process, which is usually performed under inert conditions, results in formation of a solid product [biomass] having improved energy density and physical properties (including, but not limited to hydrophobicity, grindability, pellet ability, sphericity and specific surface area). Torrefaction process, besides leading to the formation of solid product(s), may also release condensable and non-condensable gases including, but not limited to tars, CO, CO₂, H₂, CH₄ and C₂H₄. By the time each biomass bale (3) passes from top of the second chamber (1b) to the bottom of the second chamber (1b), it would have undergone torrefaction

completely. Completion of torrefaction renders each biomass bale apt for usage in downstream located thermal plants for generation of energy. It is important to note that the gases used for torrefaction contain less than 5% oxygen at all times and is an active control parameter. As the flue gases (FG) at elevated temperatures pass through the biomass bales, appropriate regulation of the mass flux and the temperature ensures partial release of volatiles [devolatilization], resulting in loss of weight of each biomass bale by less than 20% and in the course losing about 10% of the calorific value.

[0055] The torrefaction process releases products (P) which may include some residual gases and some higher hydrocarbons which may be purged from an outlet (1e) defined at the top portion of the second chamber (1b), preferably proximal to the transition section (1c). The products (P) of torrefaction may also carry the flue gas (FG) discharged into the second chamber (1b) for torrefaction. The product (P) may pass through line (L) and may be subjected to combustion [burning] by a combustion device (11) located downstream of the outlet (1e). The combustion device (11) may be charged with an air-fuel mixture to generate flame which may be used to combust or burn the incoming products (P) of torrefaction. In an embodiment, the combustion device (11) may be a generic burner. The combustion of products (P) of torrefaction may break down higher hydrocarbons present in the products (P) into products of combustion i.e., carbon dioxide CO₂ and water H₂O, along with some simple hydrocarbons. This is necessary for ensuring emission compliance and norms. In an exemplary operational embodiment, post the torrefaction, the flue gas (FG) may be passed on to the first chamber (1a). Essentially, the path of the flue gas may be such that it may be allowed to first pass through the torrefaction zone i.e., through the second chamber (1b), followed by high temperature thermal region for conditioning, and finally through the drying zone i.e., the first chamber (1a) before being released into the atmosphere, with a possible of low-grade heat recovery. This may be attained by the closed-circuit configuration of the system (100) as illustrated in Fig. 1. In an embodiment, the flue gas (FG) may be supplied from external supply (9) including, but not limited to direct combustion of LPG/CNG/PNG in a combustion engine, a gasification system, a torrefied product burner or a power plant exhaust, so that the desired temperatures inside the first chamber (1a) and second chamber (1b) may be maintained. The flue gas (FG) so supplied from the external supply (9) may mix [depicted as 'M'] with the products of torrefaction (P) [after undergoing combustion at the combustion device (11)]

and the spent flue gas from the second chamber (1b). In an embodiment, the flue gas supply (9) may be disposed downstream of the combustion device (11), although in one possibility it may be disposed on upstream side of the combustion device (11).

5 [0056] In an embodiment, the system (100) may include a heat exchanging unit (7) coupled between the flue gas supply (9) and the second chamber (1b), and also between the flue gas supply (9) and the flow creation device (6). The heat exchanging unit (7) may be intended to regulate temperature of the flue gas (FG) supplied to the second chamber (1b) for the torrefaction of the plurality of biomass bales (3). Additionally, heat exchanging unit (7) may be intended to regulate
10 temperature of the flue gas (FG) supplied to the first chamber (1a) via the flow creation device (6). In an embodiment, the heat exchanging unit (7) may be a non-contact type heat exchanger which may typically be of parallel current, counter current, cross current or mixed flow type heat exchangers. In an embodiment, the heat exchanging unit (7) may be a shell and tube type heat exchanger, plate-shell heat exchanger, tube in tube heat exchangers, or any other heat exchanger
15 which may serve the purpose. Temperature regulation by the heat exchanging unit (7) may be brought about by means of a controller [not shown] which may control several parameters, including but not limited to flow rate of the fluids and using fluids with high heat transfer [convective] coefficients and so on. An appropriate controller logic such as Proportional-Integral-Derivative (PID) control, feed forward control and internal model control may be incorporated
20 into the controller to perform the temperature regulation. In an embodiment, the heat exchanging unit (7) may be divided into two segments i.e., a first segment (7a) and a second segment (7b), both segments adapted to receive the mixture (M). The first segment (7a) may be thermally and fluidly associated with the second chamber (1b), while the second segment (7b) may be thermally and fluidly associated with the first chamber (1a) though the flow creation device (6). Both first
25 and second segments may have different control strategies such that the flue gas (FG) temperature regulation may be different for the first segment (7a) in comparison to the second segment (7b). In an embodiment, the first segment (7a) of the heat exchanging unit (7) may lower the temperature of the mixture (M) [flue gas (FG) from supply (9) and combustion products of torrefaction (P) from device (11)] to render the mixture suitable for torrefaction. Similarly, the second segment
30 (7b) of the heat exchanging unit (7) may lower the temperature of the mixture (M) to render the mixture (M) suitable for drying in the first chamber (1a), with dilution air device (8) reducing the

temperature further. In an embodiment, the heat exchanging unit (7) may recover heat for heating/preheating the biomass bales (3).

[0057] In an embodiment of the present disclosure, the system (100) may include a cooling station (12) adapted to receive plurality of torrefacted biomass bales (3T) from the second chamber (1b) for cooling the plurality of torrefacted biomass bales (3T) to a predetermined temperature. The cooling station (12) may have a third conveyer (12a) which transports the plurality of torrefacted biomass bales (3T) in heat exchanging communication with at least one coolant (5). The coolant may be stored in a storage tank or a container, as shown, so that heat may be transferred to the coolant (5) by the torrefacted biomass (3T) to cool down. Further, a transfer unit (13) may be disposed between the cooling station (12) and the second chamber (1b). For example, the transfer unit (13) may be an air-lock rotary valve which collects the torrefacted biomass (3T) after torrefaction process and delivers it to the cooling station (12) where torrefacted biomass (3T) may be cooled down before it is allowed to interact with the ambient conditions i.e., atmosphere. The cooled biomass bales may be referenced by numeral (3D). Thus, the transfer unit (13) is intended to provide an inert [isolated] atmosphere during transfer of the plurality of torrefacted biomass bales (3T) from the second chamber (1b) to the cooling station (12). The process flow illustrating the method embodiment by which biomass bales (3) are processed is depicted in **Fig. 2**.

[0058] Experimental study was conducted to evaluate the torrefaction process of straws with respect to the temperature and the exposure time. The experiments were conducted using rice straw by utilizing hot flue gas stream from a petrol engine as the source of energy for drying and torrefaction of biomass.

[0059] **Fig. 3** illustrates a schematic of an experimental set-up (300) for torrefaction of straw samples using engine exhaust as an energy source, according to an embodiment of the present disclosure. The experimental setup includes a cylindrical quartz reactor below which a provision for hot gas supply from an engine was provided. Inside the cylindrical reactor, a perforated grate was fitted at the bottom to support the sample. The hot gas supply line was connected at the bottom of the reactor which would carry the exhaust gases from the gasoline engine. The hot gas supply line was insulated to maintain the hot gas temperature to carry out the torrefaction process. The

temperature of the gas was monitored by installing a K-type thermocouple just below the grate and another thermocouple was used to measure the sample bed temperature during the process. The set-up also included a provision to cool down the torrefied biomass to avoid possible oxidation of the sample in hot conditions.

5 [0060] Sample preparation involved packing of rice straw into a cylindrical shape in such a way that the bulk density remained about 100 kg/m³ similar to the straw bales. In present case of experiments, as received biomass was used which carried moisture with it. In a separate experiment the moisture content was evaluated as 10%. Before sample loading, the hot flue gas was allowed
10 to pass through the reactor till the temperature of the gas attained intended temperature. The biomass was loaded into the reactor when the hot gas temperature reached a constant value of intended temperature. To control the temperature of the flue gas near the sample, insulation of flue gas supply line was varied as the temperature of torrefaction process has to be limited to a maximum of 300 °C. On sample loading, the biomass bed temperature would increase from
15 ambient to the stream temperature or beyond after coming into direct contact with the hot gas. A constant mass flux of exhaust gas was sent through the biomass bed for the process. Biomass released moisture and a fraction of volatiles on coming in direct contact with the hot gas stream. The biomass sample was exposed to the constant temperature hot flue gas stream for a pre-decided amount of time and engine was switched off. The biomass sample bed was allowed to cool in an
20 inert environment by supplying nitrogen till the torrefied biomass temperature reached below 150 °C. The sample was subjected to the torrefaction process even after the engine was switched off as it took some time for the temperature to come down to 150 °C. The sample was unloaded, and physical inspection of the sample was done to ensure the uniformity of the process and its weight was recorded.

25 [0061] Figs. 4A and 4B present the graphical illustrations of temperature of the bed over the period of experiments at two different hot flue gas temperatures. Fig. 4A shows that the biomass bed spent about 17 minutes at temperature 200 – 250 °C. The biomass was inspected, and the weight loss was found to be about 17%. The maximum temperature of the biomass was limited to
30 250 °C in the first case depicted in Fig. 4A. In Fig. 4B, the maximum temperature of the biomass was maintained at 280 °C while it only spent 11 minutes above 200 °C and the mass loss recorded

was about 21%. The experiments show that more than exposure time, to achieve torrefaction, the temperature plays an important role. On comparison of the torrefaction product, it was found that the quality was better in the latter case (Fig. 4B).

5 [0062] The system and the method disclosed in the present disclosure have several inherent advantages. One advantage is that the need for tedious and time-consuming pre-processing and preparation of the biomass bales may be eliminated. In other words, biomass bales in raw and crude form may be directly fed into the reaction chamber, without the need for preprocessing. This helps in significant saving of man hours, machine hours and capital. Another advantage is the
10 flexibility to regulate the temperatures required for drying and torrefaction to process a wide range of biomass categories, including the agricultural waste. Yet another advantage is the compactness of the reaction chamber due to integration of the drying and torrefaction sections in a single reaction chamber. This is beneficial in substantial savings of capital and time involved in manufacturing the reaction chamber, while providing flexibility to modify the reaction chamber
15 design conveniently to suit various processing plant capacities.

20 **Equivalents:**

[0063] With respect to the use of substantially any plural and/or singular terms herein, those having skill in the art can translate from the plural to the singular and/or from the singular to the plural as is appropriate to the context and/or application. The various singular/plural permutations
25 may be expressly set forth herein for sake of clarity.

[0064] It will be understood by those within the art that, in general, terms used herein, and especially in the appended claims (e.g., bodies of the appended claims) are generally intended as "open" terms (e.g., the term "including" should be interpreted as "including but not limited to," the
30 term "having" should be interpreted as "having at least," the term "includes" should be interpreted as "includes but is not limited to," etc.). It will be further understood by those within the art that if a specific number of an introduced claim recitation is intended, such an intent will be explicitly recited in the claim, and in the absence of such recitation no such intent is present. For example,

as an aid to understanding, the following appended claims may contain usage of the introductory phrases "at least one" and "one or more" to introduce claim recitations. However, the use of such phrases should not be construed to imply that the introduction of a claim recitation by the indefinite articles "a" or "an" limits any particular claim containing such introduced claim recitation to inventions containing only one such recitation, even when the same claim includes the introductory phrases "one or more" or "at least one" and indefinite articles such as "a" or "an" (e.g., "a" and/or "an" should typically be interpreted to mean "at least one" or "one or more"); the same holds true for the use of definite articles used to introduce claim recitations. In addition, even if a specific number of an introduced claim recitation *is* explicitly recited, those skilled in the art will recognize that such recitation should typically be interpreted to mean *at least* the recited number (e.g., the bare recitation of "two recitations," without other modifiers, typically means *at least* two recitations, or *two or more* recitations). Furthermore, in those instances where a convention analogous to "at least one of A, B, and C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, and C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). In those instances where a convention analogous to "at least one of A, B, or C, etc." is used, in general such a construction is intended in the sense one having skill in the art would understand the convention (e.g., "a system having at least one of A, B, or C" would include but not be limited to systems that have A alone, B alone, C alone, A and B together, A and C together, B and C together, and/or A, B, and C together, etc.). It will be further understood by those within the art that virtually any disjunctive word and/or phrase presenting two or more alternative terms, whether in the description, claims, or drawings, should be understood to contemplate the possibilities of including one of the terms, either of the terms, or both terms. For example, the phrase "A or B" will be understood to include the possibilities of "A" or "B" or "A and B."

[0065] While various aspects and embodiments have been disclosed herein, other aspects and embodiments will be apparent to those skilled in the art. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

Table of reference numerals

Component/Step	Numeral
System for processing biomass	100
Reaction chamber	1
First chamber	1a
Second chamber	1b
Transition section	1c
First conveyer	1d
Outlet	1e
Loading station	2
Second conveyer	2a
Plunger	2b
Biomass bales	3
Dried biomass bales	3D
Torrefacted biomass bales	3T
Cooled biomass bales	3C
Exhaust hood	4
Coolant	5
Flow creation device	6
Heat exchanging unit	7
First and second segments of heat exchanging unit	7a and 7b
Dilution air device	8
Flue gas supply	9
Combustion device	11
Cooling station	12

Third conveyer	12a
Transfer unit	13
Drying side	DS
Torrefaction side	TS
First channels	FC
Second channels	SC
Opening in first chamber	OP
First inlet	FI
Second inlet	SI
Products of torrefaction	P
Line	L
Flue gas	FG
Mixture	M
Experimental set up	300

The Claims:

1. A system (100) for processing biomass, the system (100) comprising:

a reaction chamber (1), comprising:

5 a first chamber (1a) adapted to receive a plurality of biomass bales (3) from a loading station (2), wherein the first chamber (1a) is configured to dry each of the plurality biomass bales (3) by passage of a flue gas (FG) into the first chamber (1a) at a first predetermined temperature range and a first predetermined flue gas flux range, and

10 a second chamber (1b) located adjacent to the first chamber (1a), the second chamber (1b) adapted to receive the plurality of biomass bales (3) from the first chamber (1a), wherein each of the plurality of biomass bales undergoes torrefaction at the second chamber (1b) by passage of the flue gas (FG) into the second chamber (1b) at a second predetermined temperature range and a second predetermined flue gas flux range; and

15 a first conveyer (1d) bridging the first chamber (1a) and the second chamber (1b), and configured to transport the plurality of biomass bales (3) from the first chamber (1a) to the second chamber (1b).

- 20 2. The system (100) as claimed in claim 1, wherein the loading station (2) comprises:

a second conveyer (2a) including a plurality of provisions, each provision structured to support and transport one of the plurality of biomass bales (3); and

25 at least one plunger (2b) disposed proximal to an opening (OP) defined in the first chamber (1a), the at least one plunger (2b) configured to assist in loading each of the plurality of biomass bales (3) into the first chamber (1a) through the opening (OP).

- 30 3. The system (100) as claimed in claim 1, wherein the second chamber (1b) comprises an outlet (1e) defined at a top portion to purge products of torrefaction (P) from the second chamber (1b).

4. The system (100) as claimed in claims 1 and 3 comprises a flue gas supply (9) fluidly disposed downstream of the outlet (1e), the flue gas supply (9) is configured to supply the flue gas (FG) to the first chamber (1a) for drying the plurality of biomass bales (3), and the second chamber (1b) for the torrefaction of the plurality of biomass bales (3).
5. The system (100) as claimed in claims 1 and 4, comprises:
- a plurality of first channels (FC) defined in the first chamber (1a), wherein the plurality of first channels (FC) are fluidly coupled to the flue gas supply (9), and configured to channelize the flue gas (FG) at the first predetermined flue gas flux range into the first chamber (1a); and
- a plurality of second channels (SC) defined in the second chamber (1b), wherein the plurality of second channels (1b) are fluidly coupled to the flue gas supply (9), and configured to channelize the flue gas (FG) at the second predetermined flue gas flux range into the second chamber (1b).
6. The system as claimed in claim 5 comprises at least one flow control valve configured to regulate flow of the flue gas (FG) into the first chamber (1a) and the second chamber (1b).
7. The system (100) as claimed in claim 4 comprises a heat exchanging unit (7) coupled between the flue gas supply (9) and the second chamber (1b), the heat exchanging unit (7) is configured to regulate temperature of the flue gas (FG) supplied to the second chamber (1b) for the torrefaction of the plurality of biomass bales (3).
8. The system (100) as claimed in claims 1-5 comprises a flow creation device (6) configured to distribute the flue gas (FG) between the loading station (2) and the first chamber (1a).
9. The system (100) as claimed in claim 8 comprises a dilution air device (8) fluidly disposed between the first chamber (1a) and the flow creation device (6), wherein the dilution air device (8) is configured to discharge diluted air into the flue gas (FG) flowing into the first chamber (1a).

10. The system (100) as claimed in claim 1 comprises a cooling station (12) adapted to receive plurality of torrefacted biomass bales (3T) from the second chamber (1b) for cooling the plurality of torrefacted biomass bales (3T) to a predetermined temperature, wherein the cooling station (12) includes a third conveyer (12a) configured to transport the plurality of torrefacted biomass bales (3T) in heat exchanging communication with at least one coolant (5).
11. The system as claimed in claim 10 comprises a transfer unit (13) disposed between the cooling station (12) and the second chamber (1b), the transfer unit (13) is configured to provide an inert atmosphere for transfer of the plurality of torrefacted biomass bales (3T) from the second chamber (1b) to the cooling station (12)
12. The system (100) as claimed in claim 1, wherein the first predetermined temperature for drying the plurality of biomass bales (3) ranges from 100 °C to 175 °C, and the second predetermined temperature for torrefacting the plurality of biomass bales (3) ranges from 250 °C to 350 °C.
13. The system as claimed in claims 1 and 12, wherein the first predetermined flue gas flux for drying the plurality of biomass bales (3) ranges from 150+/-25 gm/m²-sec to 100+/-25 gm/m²-sec, and the second predetermined flue gas flux for torrefacting the plurality of biomass bales (3) ranges from 275+/-25 gm/m²-sec to 200+/-25 gm/m²-sec.
14. A method for processing biomass, the method comprising:
- receiving, by a first chamber (1a) defined in a reaction chamber (1), a plurality of biomass bales (3) from a loading station;
 - drying, in the first chamber (1a), the plurality of biomass bales (3) at a first predetermined temperature range and a first predetermined flue gas flux range by passage of flue gas (FG) into the first chamber (1a);
 - transporting, by a first conveyer (1d), the plurality of biomass bales (3) from the first chamber (1a) to a second chamber (1b) located adjacent to the first chamber (1a),

wherein the first conveyer (1d) bridges the first chamber (1a) and the second chamber (1b); and

torrefacting, in the second chamber (1b), the plurality of biomass bales (3) at a second predetermined temperature and a second predetermined flue gas flux range, by passage of the flue gas (FG) into the second chamber (1a).

15. The method as claimed in claim 14 comprises removing moisture containing gases from the first chamber (1a) through an exhaust hood (4) after drying the plurality of biomass bales (3).

16. The method as claimed in claim 14 comprises supplying, by a flue gas supply (9), the flue gas (FG) to the first chamber (1a) for drying the plurality of biomass bales (3), and the second chamber (1b) for the torrefaction of the plurality of biomass bales (3).

17. The method as claimed in claims 14 and 16 comprises distributing the flue gas (FG) to the first chamber (1a) and the loading station (2) by a flow creation device (6), wherein the flow creation device (6) is fluidly disposed between the loading station (2) and the first chamber (1a).

18. The method as claimed in claim 17 comprises discharging diluted air into the flue gas (FG) by a dilution air device (8), wherein the dilution air device (8) is fluidly disposed between the first chamber (1a) and the flow creation device (6).

19. The method as claimed in claims 11-15 comprises regulating temperature of the flue gas (FG) supplied to the second chamber (1b) by a heat exchanging unit (7), wherein the heat exchanging unit (7) is coupled between the flue gas supply (9) and the second chamber (1b).

20. The method as claimed in claims 14 and 16 comprises regulating, by at least one flow control valve, flow of the flue gas (FG) into the first chamber (1a) and the second chamber (1b).

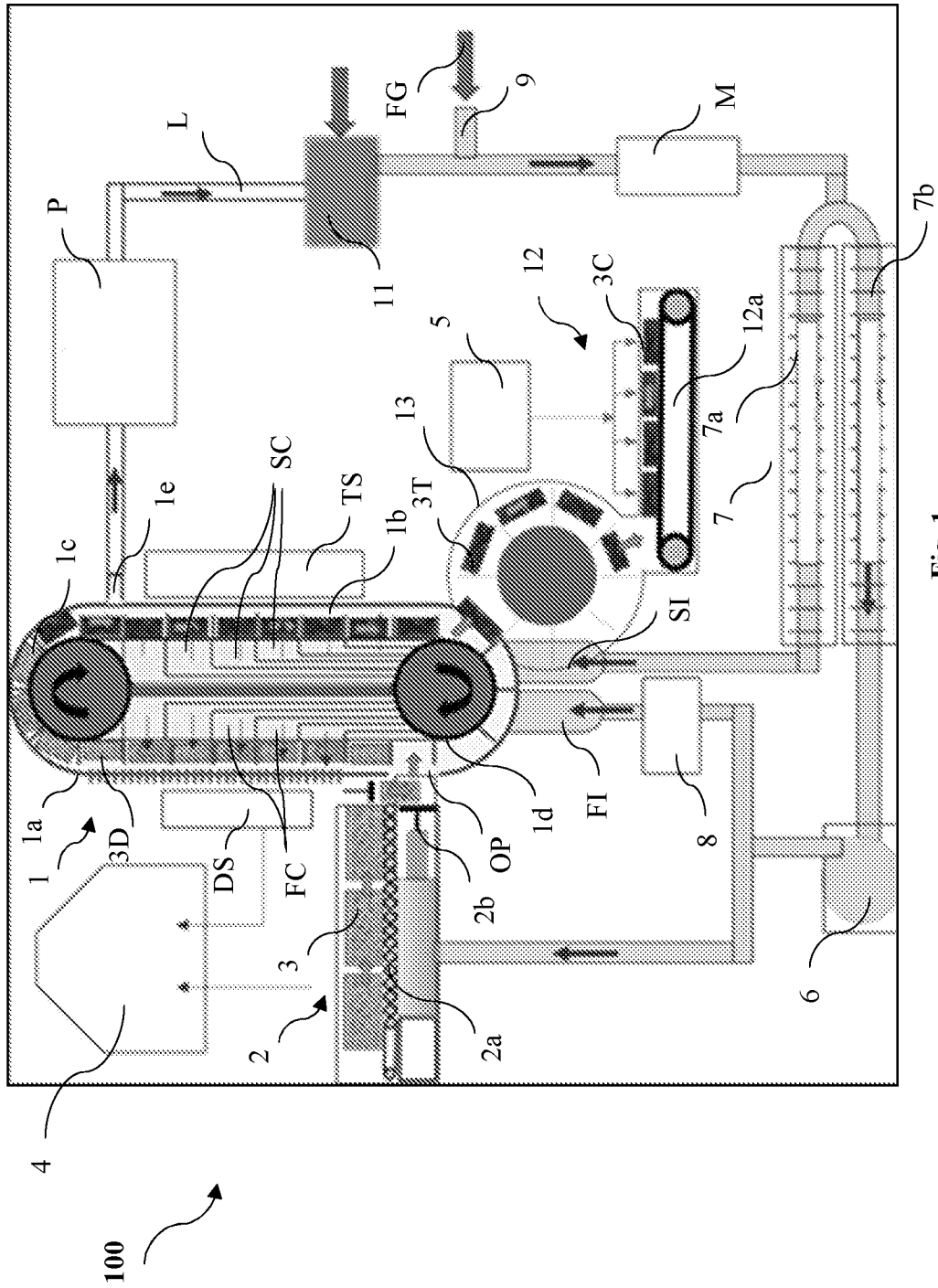
21. The method as claimed in claim 14 comprises combusting products of the torrefaction by a combustion device (11) disposed downstream of the second chamber (1b).

22. The method as claimed in claim 14 comprises cooling, at a cooling station (12), each of
5 plurality of torrefacted biomass bales (3T) exiting from the second chamber (1b), wherein
the cooling station (12) includes a third conveyer (12a) configured to transport the plurality
of torrefacted biomass bales (3T) in heat exchange communication with at least one coolant
(5).

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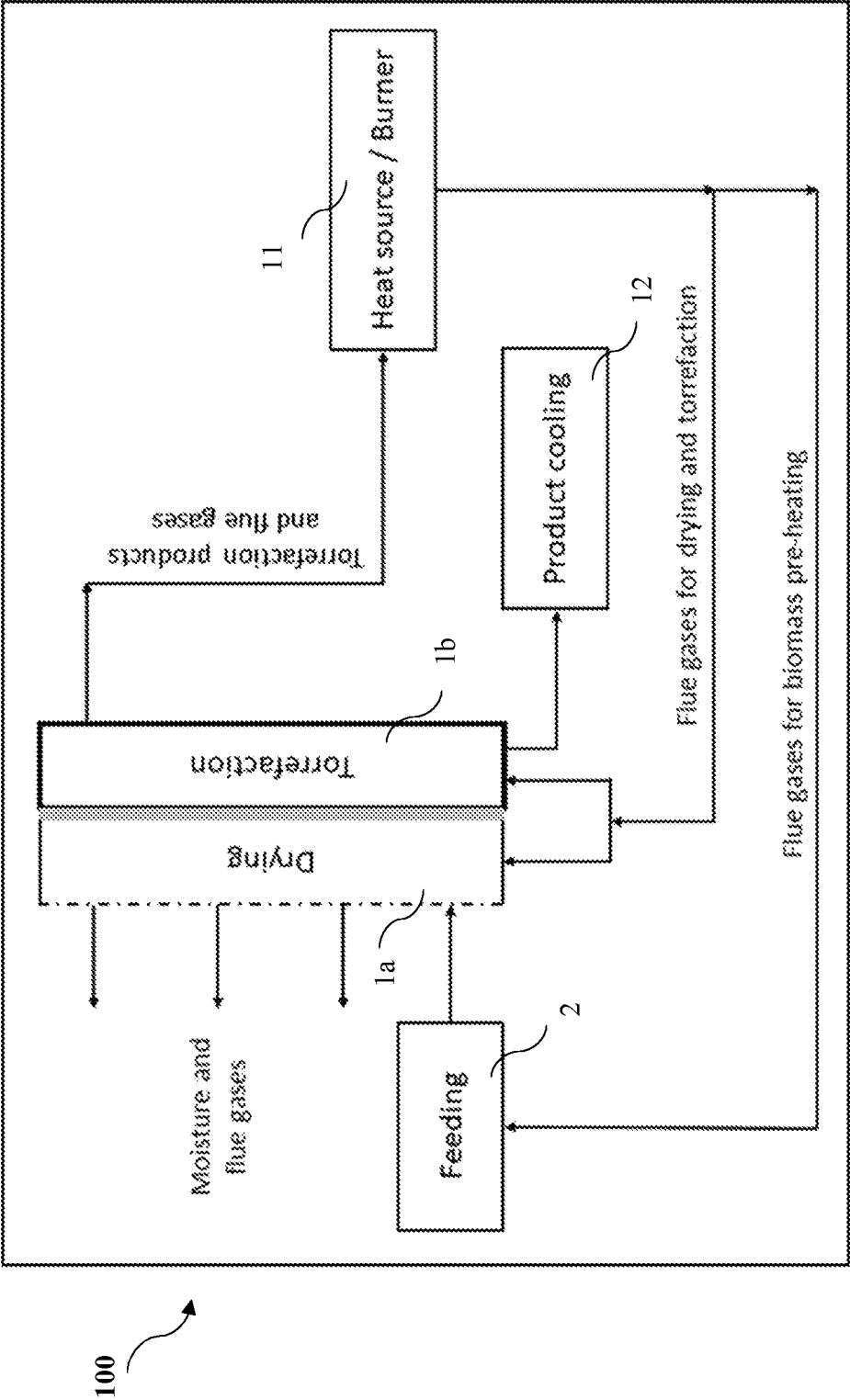


Fig. 2

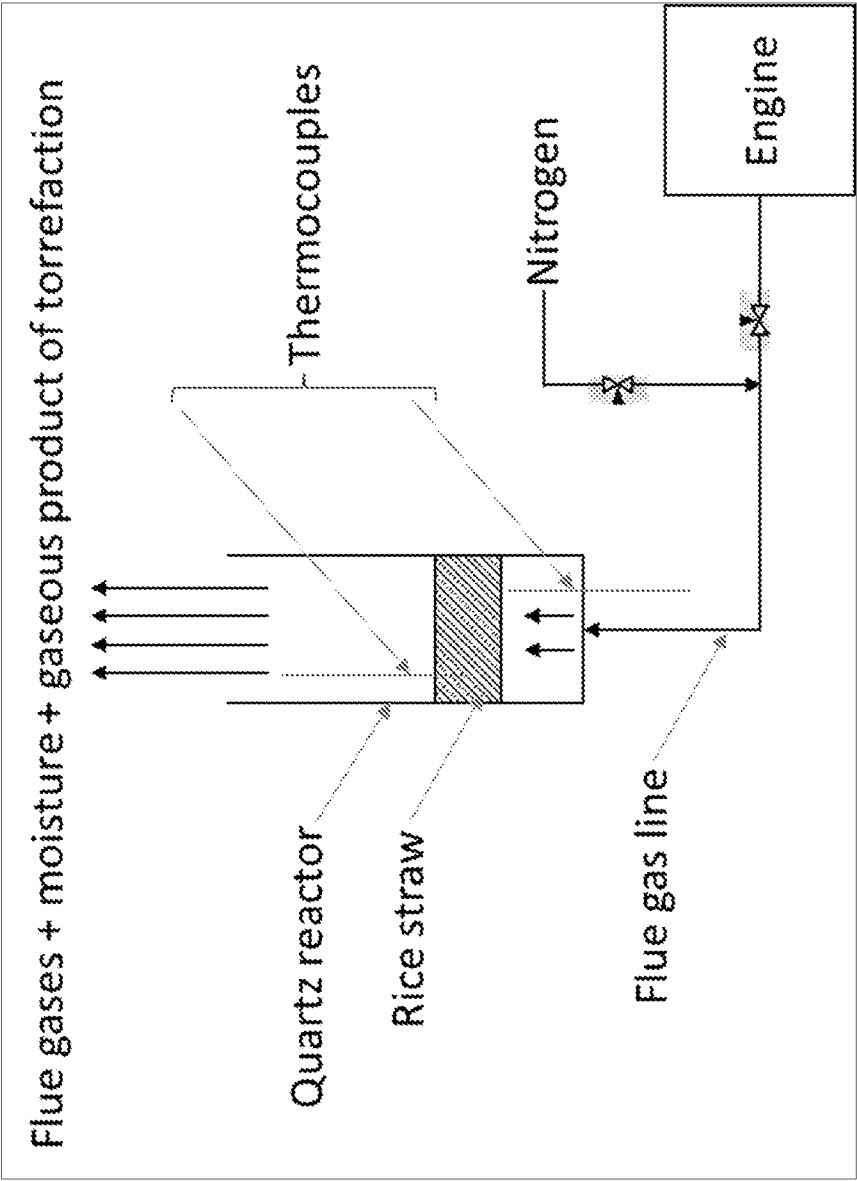


Fig. 3

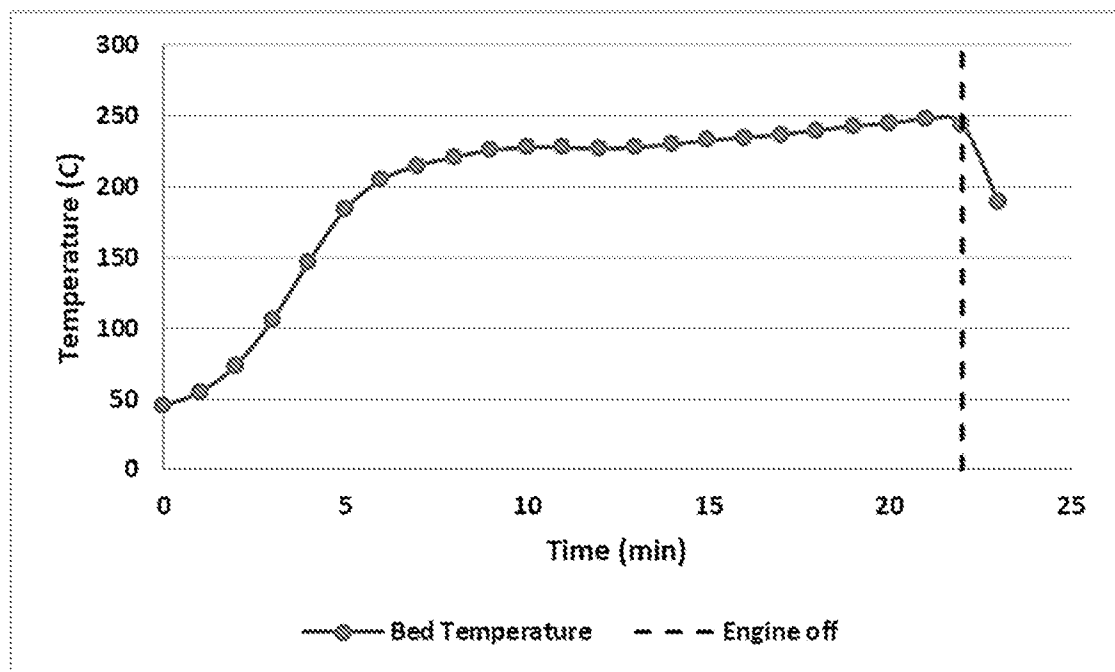


Fig. 4A

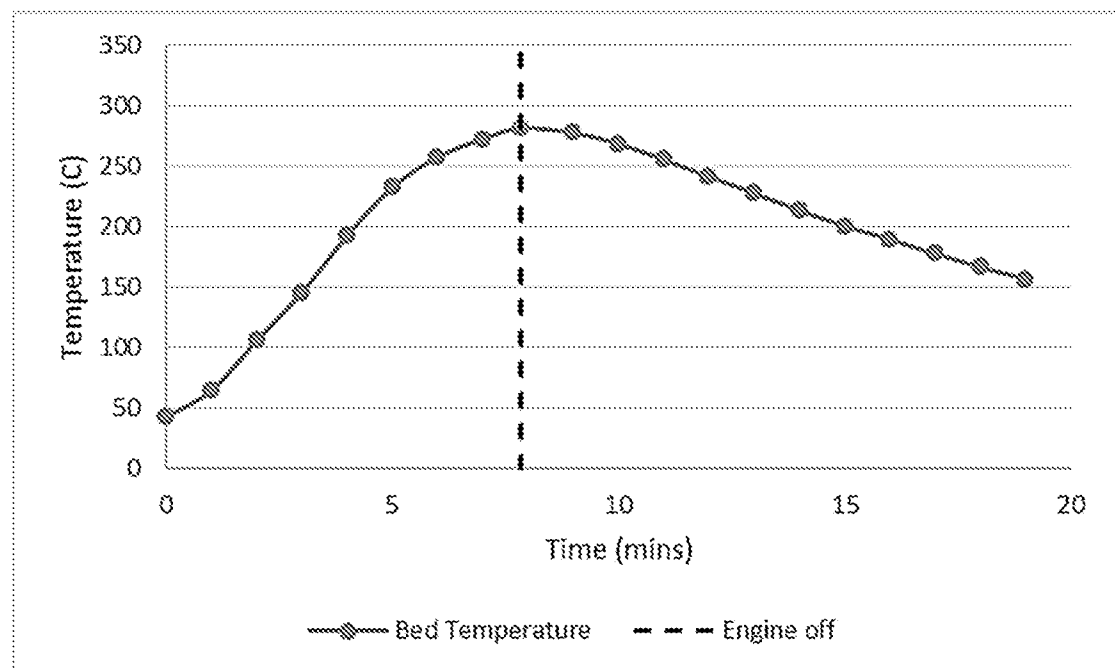


Fig. 4B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2022/050295

A. CLASSIFICATION OF SUBJECT MATTER
C10L9/08, F26B17/16 Version=2022.01

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, F26B

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PatSeer, IPO Internal Database

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	EP2543718A1 ; (Energa Elektrownie Ostroleka SA et al); (09 JANUARY 2013) [PARA 14- PARA 44 ; Claims 1-15; Figure 1]	1-22
Y	WO2019166873A1 ; (Darko GORICANEC) ; (6 SEPTEMBER 2019) [PARA11- PARA 28 ; Claims 1-19; Figure 1-2]	1-22

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

* Special categories of cited documents:

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"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

"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

"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

"&" document member of the same patent family

Date of the actual completion of the international search

29-04-2022

Date of mailing of the international search report

29-04-2022

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IB2022/050295

Citation	Pub.Date	Family	Pub.Date
EP 2543718 A1	09-01-2013	EP 2543717 A1	09-01-2013
WO 2019166873 A1	06-09-2019	SL 25600 A	30-08-2019