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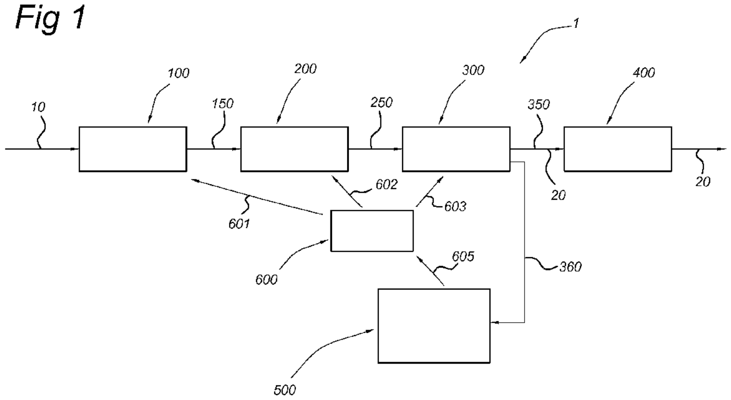
(54) Title: APPARATUS AND PROCESS FOR THE THERMAL TREATMENT OF BIOMASS

Fig 1



(57) Abstract: The invention provides an apparatus for the thermal treatment of biomass, comprising (1) a low-temperature drying section comprising a low-temperature drying section channel with low-temperature drying section channel (screw) transporter, (2) a high-temperature drying section comprising a high-temperature drying section channel with high-temperature drying section channel (screw) transporter, (3) a torrefaction section comprising a torrefaction channel with torrefaction section channel (screw) transporter, (4) a cooling section comprising a cooling section channel with cooling section channel (screw) transporter, (5) a torrefaction section off-gas combustor, (6) a thermal energy transfer system, in thermal contact with the torrefaction section off-gas combustor and one or more of the torrefaction section, the high-temperature drying section and the low-temperature drying section.

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Apparatus and process for the thermal treatment of biomass

Field of the invention

The invention relates to an apparatus for the thermal treatment of biomass and to a process for the thermal treatment of biomass, especially with such apparatus. The invention further relates to a torrefied product obtainable by such process for the thermal treatment.

Background of the invention

The thermal treatment of biomass is known in the art. WO2010124077, for instance, describes several variations for converting biomass, and other carbon-containing feedstocks, into syngas. Some variations include pyrolyzing or torrefying biomass in a devolatilization unit to form a gas stream and char, and gasifying the char. Other variations include introducing biomass into a fluid-bed gasifier to generate a solid stream and a gas stream, followed by a partial-oxidation or reforming reactor to generate additional syngas from either, or both, of the solid or gas stream from the fluid-bed gasifier. Hot syngas is preferably subjected to heat recovery. The syngas produced by the disclosed methods may be used in any desired manner, such as conversion to liquid fuels (e.g. ethanol).

WO2010115563 describes a method and an apparatus for producing biocoke from plant biomass, said biocoke being suitable for gasification in an entrained-flow reactor. The method includes the steps of comminuting, drying, and mixing the biomass and subjecting the comminuted biomass to torrefaction until a solid residue is formed. The torrefaction process is carried out in a fluidized-bed system that comprises a bed region having a high solid concentration and a free space thereabove having a low solid concentration.

US2010242351 describes methods and systems for preparing a torrefied biomass fuel. Moisture is initially extracted from relatively wet biomass fuel to produce a relatively dry biomass fuel. Remaining moisture is then extracted from the relatively dry biomass fuel in a final drying stage, using steam at a temperature of about 900 °F. The resulting dried biomass fuel is conveyed downward using gravity and undergoes torrefaction, which produces torrefied biomass fuel and torrefaction gases. A gaseous mixture of steam and torrefaction gases is vented to a heat exchanger, where the gaseous mixture is heated by a flue gas, and the heated gaseous mixture is used to support the extraction of the remaining moisture in the final drying stage and to support the torrefaction of the dried biomass fuel. Embodiments described in US2010242351 may use available energy resources to the benefit of manufacturers, consumers, and the environment.

Summary of the invention

A disadvantage of prior art apparatus and methods may for instance be their efficiency and their ability to control pelletizability of the torrefied biomass.

Hence, it is an aspect of the invention to provide an alternative apparatus and alternative method, which preferably further at least partly obviate one or more of above-described drawbacks.

In a first aspect, the invention provides an apparatus for the thermal treatment of biomass, comprising (1) a low-temperature drying section comprising a low-temperature drying section channel with low-temperature drying section channel (screw) transporter, (2) a high-temperature drying section comprising a high-temperature drying section channel with high-temperature drying section channel (screw) transporter, (3) a torrefaction section comprising a torrefaction channel with torrefaction section channel (screw) transporter, (4) a cooling section comprising a cooling section channel with cooling section channel (screw) transporter, (5) a torrefaction section off-gas combustor, (6) a thermal energy transfer system, in thermal contact with the torrefaction section off-gas combustor and one or more of the torrefaction section, the high-temperature drying section and the low-temperature drying section.

In a further aspect, the invention provides a process for the thermal treatment of biomass comprising (a) providing biomass, (b) transporting the biomass through a low-temperature drying section, a high-temperature drying section, a torrefaction section and a cooling section, with one or more screw transporters, (c) drying in a low-temperature drying process the biomass at a temperature in the range of 90-120 °C in the low-temperature drying section, (d) drying in a high-temperature drying process the biomass at a temperature in the range of 150-220 °C in the high-temperature drying section, (e) torrefying in a torrefying process the biomass a temperature in the range of 200-300 °C in the torrefaction section to produce torrefied biomass and off-gas, (f) cooling in a cooling process the torrefied biomass in the cooling section, (g) combusting in a combustion process at least part of the off-gas to produce thermal energy, (h) transferring at least part of the thermal energy to one or more of the low-temperature drying process, the high-temperature drying process, and the torrefying process. Especially, the invention provides such process wherein the apparatus according to the invention is applied.

An advantage of such apparatus and such process may be the thermal efficiency. The apparatus and process may operate autothermal at a relatively high energy efficiency. Further, the apparatus and process may allow tuning process parameters in such a way, that the water content of the torrefied may be controlled. This may especially be advantageous when pelletizing the torrefied biomass. Further, advantageously, the density of the torrefied biomass may be controlled. Often, relatively porous pellets are desired when co-firing the torrefied biomass pellets as fuel in, for instance, a combustion plant.

In the context of the invention, the terms "method" and "process" are considered synonymous. The term “apparatus” may in an embodiment also refer to a plurality of such apparatus, for instance parallelly arranged apparatus for executing parallelly the process of the invention. This may increase the throughput of the apparatus. One or more apparatus may also be considered a (small-scale) plant. The term “thermal treatment” may in an embodiment include “thermal pre-treatment”. In general, the torrefied biomass may be used for auxiliary fuel in waste incineration plants or in fossil fuel plants, especially those based on a broad variety of coal ranks. Hence, the process of the invention may in an embodiment also be considered as a process for the thermal pre-treatment of biomass. The term “biomass” may refer to biological material from living, or formerly living organisms, such as wood, plant material and municipal organic waste. Herein, the term biomass especially refers agricultural waste, such as preferably to one or more of straw and hay. Especially those materials appear to be well processable with the apparatus of the invention. The biomass before the low-temperature drying process may have a water content in the range of 5-25 wt.%, preferably 5-20 wt.%.

In a preferred embodiment, the apparatus further comprises a grinding section, arranged upstream of the low-temperature drying section. For instance, the apparatus may comprise a grinder comprising said grinding section. In a further embodiment, a plurality of grinders may be applied.

The grinding section is especially configured to grind the biomass, such as hay or straw, which can for instance be in the form of straw and hay bales, to particles of sizes between a 0.1 mm and 10 cm, especially between 1 mm and 10 cm. Preferably, at least 80 wt.% of the biomass is provided (to the low-temperature drying section) as particulate material having the indicated particle sizes. The grinding action may in an embodiment be based on a fast rotating drum, or hammer mills, especially the former equipped with for instance knives taking care of both cutting and grinding at the same time. In this process a lot of air born dust may be released which, due to a small overpressure generated by the drum, is being returned to the input section. This precaution may prevent release of dust to the environment.

Hence, the process of the invention may further comprise grinding the biomass before subjecting to the low-temperature drying process.

Preferably, the transporters in the low-temperature drying section, in the high-temperature drying section, in the torrefaction section, and optionally in the cooling section, are based on a screw-type conveyor (herein indicated as screw transporter), which preferably rotate in a cylindrical or U-shaped trough.

In an embodiment, the low-temperature drying section channel screw transporter and the high-temperature drying section channel screw transporter are independently selected from the group consisting of a full blade screw transporter, a ribbon blade screw transporter and a perforated blade screw transporter. Those transporters can also be indicated as screw conveyors. In an embodiment, the low-temperature drying section channel screw transporter, the high-temperature drying section channel screw transporter, and optionally the cooling section channel screw transporter are full screw blade transporters.

In a further embodiment, the torrefaction screw transporter is preferably a ribbon blade screw transporter or perforated blade screw transporter, preferably a ribbon blade screw transporter, even more preferably a ribbon blade screw transporter with blade extensions, for instance arranged substantially parallel to the screw axis. The use of a perforated blade screw transporter in the drying sections is preferred to especially facilitate drying air through the biomass bed in a direction parallel to the screw axis. In the torrefaction section it may especially facilitate heat transfer within the torrefaction channel since the material within the torrefaction channel will not only move in the transport direction, but part may also move in an opposite direction, due to perforation(s) in the blades. Hence, intimate mixing of the product and good thermal transfer may thereby be facilitated.

Hence, in a further aspect, the invention provides a torrefaction unit (or reactor), comprising a torrefaction section, the torrefaction section comprising a torrefaction channel with torrefaction section channel screw transporter, wherein the torrefaction screw transporter is preferably a ribbon blade screw transporter or perforated blade screw transporter, preferably a ribbon blade screw transporter, even more preferably a ribbon blade screw transporter with blade extensions parallel to the screw axis.

As indicated above, the cooling section channel screw transporter may especially be full screw blade transporter.

Hence, the biomass is transported through the low-temperature drying section, the high-temperature drying section, the torrefaction section and the optional cooling section, with one or more (screw) transporters, wherein preferably at least in the low-temperature drying section, the high-temperature drying section, and the torrefaction section the biomass is transported with screw transporters.

In an embodiment, at least part the low-temperature drying section channel, at least part of the high-temperature drying section channel and at least part of the torrefaction section channel are cylindrical or U-shaped (U-shaped trough). In an embodiment at least part the low-temperature drying section channel, at least part of the high-temperature drying section channel and at least part of the torrefaction section channel may also be tube shaped or cylindrically shaped. It may be advantageous to have both shapes, i.e. a part of the channel being U-shaped and part of the channel being tube shaped. Especially, the U-shape may effectively allow thermal energy transfer and gas transport, and may reduce blocking of product during transport through the channel(s).

A drawback of a U shaped (cooling section) channel might be that drying air will not contact the biomass bed over the full height as it will follow a low resistance path above the screw where biomass may be not present. Therefore, in a further embodiment, at least part of the cooling section channel can be cylindrically shaped.

Hence, the invention provides an apparatus as described herein, wherein one or more of at least part the low-temperature drying section channel, at least part of the high-temperature drying section channel and at least part of the torrefaction section channel are cylindrically shaped. Alternatively or additionally, one or more of at least part the low-temperature drying section channel, at least part of the high-temperature drying section channel and at least part of the torrefaction section channel are U-shaped. Hence, in an embodiment, wherein one or more of those channels comprise an U-shaped part, preferably further one or more of at least another part the low-temperature drying section channel, at least another part of the high-temperature drying section channel and at least another part of the torrefaction section channel are cylindrically shaped.

It is found that the combination of direct (influx of hot gas) and indirect (via heat exchanger) supply of drying heat to the input material is a very effective way of drying. Although the mechanical contact between straw and the heated wall (which may function as heat exchanger per se, or which may receive thermal energy of a heat exchanger (in physical contact with the wall) is limited, the release of moist increases the heat transfer. At a very local scale water may evaporate out of the material and contacts with the wall, recondenses and evaporates. This effect may relate to a “heat pipe” effect at a very local scale. In effect, due to build up of moist release towards the centre of the straw package, the drying effect is homogenized over its thickness. The contact air finally removes the moist out of the package.

It is found that a homogeneous drying rate over the thickness and the length of the package is established when the length of the contact zone is more than twice the width of the tube and the total flow due to moist release is by a factor of more than 4 lower than the flow of contact air. This finding may reduce the up scaling problem of the dryers to guaranteeing sufficient contact air flow and heat transfer to the hot wall of the dryer.

The drying sections are especially configured to remove both physically and chemically bound water. The physically bound water may release already at temperatures below 120 °C and is clean enough to be released (drying section off-gas). The chemically bound water may release at temperatures of up to 160 °C, but the contact air might pick up some hydrocarbons from the input, which cannot be readily released.

For this reason, it is preferred to apply two drying sections, i.e. the low-temperature drying section and (arranged downstream thereof) the high-temperature drying section. In a specific embodiment, the high-temperature drying section receives its heat at about 170 °C. In an embodiment, a warm (hot) gas is used (especially from the thermal energy transfer system), to heat the high-temperature drying section. In a specific embodiment, the low-temperature drying section receives its heat from the heat exchanger of the high-temperature drying section and/or of the heat exchanger of torrefaction section. The water evaporated away from low-temperature drying section may be partly physically bound water produced at temperatures below for instance 110 °C, and can be released to the environment.

In a preferred embodiment, this warm gas stream is split into two parts before it enters the drying section. One part is blown directly through the high-temperature drying section channel and may take up most of the remaining moist (drying gas). Because this gas will contain/acquire, next to water, also some unwanted components being released during drying, it may be returned to the torrefaction section off-gas combustor, for instance as a gas quench medium to bring down the combustion gases to the required temperature level. This can be considered the drying gas.

As indicated above, the drying gas may especially be received from the thermal energy transfer system. Drying gas may be introduced in the channel via one or more of (1) channel openings at the ends of the channel (channel entrance for biomass and/or channel exit for (dried) biomass), one or more openings in a channel wall, and (3) via a screw transporter axis. This applies independently for the low-temperature and high temperature drying section.

The other part of the warm gas may be directed through a heat exchanger at least partly surrounding the high-temperature drying section channel, such as a trough ("U-shaped") or tube ("circularly shaped"), and indirectly dissipates its heat to the input stream. This gas may only contain the combustion products without intermixing of unwanted components (since it is not in contact with the drying biomass) and may therefore in an embodiment be used in the low-temperature dryer. This applies independently for the low-temperature and high temperature drying section.

Optionally, at least part of the gas that is directed through the heat exchanger, may subsequently be introduced in the drying section channel (as drying gas). For instance, the hot gas is transported through the mantle of the drying section channel. This applies independently for the low-temperature and high temperature drying section.

Such two-step type of drying appears to be advantageous, and may not only be beneficial in the process of the invention, but also in general. Hence, in a further aspect, the invention provides a process for drying biomass (for instance as drying treatment for a later torrefying process) in a low-temperature drying process the biomass at a temperature in the range of 90-120 °C (for instance in the herein described low-temperature drying section, and subsequently drying in a high-temperature drying process the biomass at a temperature in the range of 150-220 °C (for instance in the herein described high-temperature drying section), to provide dried biomass, such as dried hay or dried straw, and optionally torrefying in a torrefying process the biomass a temperature in the range of 200-300 °C (for instance in the herein described torrefaction section) to produce torrefied biomass and off-gas. As indicated above, the first drying process may be preceded by a grinding process (for instance in the herein described grinding section).

The low-temperature drying section may thus especially configured to perform a drying process of biomass at a temperature in the range of 90-120 °C; the high-temperature drying section may thus especially be configured to perform a drying process of biomass at a temperature in the range of 150-220 °C.

Flow of gas from the high-temperature drying section to the torrefaction section is preferably suppressed as much a possible. This may guaranteed by preventing a gas pressure difference between the high-temperature drying section and the torrefaction section and/or by a lock (or “gas lock”). The lock may for instance be a fast rotation roller device allowing the dried biomass into the torrefaction section but blocking flow of gas.

Hence, in a specific embodiment, the apparatus further comprises a lock arranged downstream of the high-temperature drying section and upstream of the torrefaction section, wherein the lock comprises at least two oppositely arranged (and oppositely rotating) rotators with a non-zero distance to each other, wherein the lock is configured to transport dried biomass from the high-temperature drying section to the torrefaction section and wherein the lock is configured to inhibit gas flow from one section to the other. The non-zero distance may for instance be in the range of 5-30% of the screw diameter of the high-temperature drying section (i.e. the rotators are adjacent).

Such lock may also be applied between other sections.

In a further aspect, the invention provides such lock per se. In a specific embodiment, the lock may comprise a plurality of such oppositely arranged rotators, which may thus be configured to provide a channel (due to the non-zero distance) between the oppositely arranged rotators for biomass transport from one section to another section.

In yet a further aspect, the invention provides two heating sections (such as here the high-temperature drying section and the torrefaction section), coupled via such lock, especially heating sections through which transport of solid material is effected by section channel screw transporters, such as defined herein.

Hence, the invention also provides a process as described herein, wherein the dried biomass is transported from the high-temperature drying section to the torrefaction section through oppositely rotating rotators with a non-zero distance to each other (for instance of a lock as described herein)

The torrefaction section receives the dried input, in an embodiment for instance by a special transfer unit, such as the above indicated lock, which separates the gas environments of the high-temperature drying section and the torrefaction section, such as the gas-lock indicated above. This precaution is preferred, as the combustible gas of the torrefaction section should preferably not be diluted with gas from the high-temperature drying section. This separation may be achieved by a mechanical transfer unit leaving the solids to pass through and suppress exchange of gases. As indicated above, control of the pressure difference between dryer and reactor will also help to suppress this exchange.

The torrefaction section may receive in an embodiment its thermal energy from (labyrinth) heat exchangers connected to the outside wall of the torrefaction section channel. Such labyrinth heat exchanger may consist of (four) sub sections which are interconnected in such a way that the optimum axial temperature distribution over the length of the torrefaction section channel, such as a trough like reactor containment, may be obtained.

Although the torrefaction process is endothermic, the heat necessary to perform the reactions is limited and therefore the transfer of heat to the torrefaction section channel in the way described is more than sufficient for the indicated fuel input and gives ample room for increasing the throughput as long as the drying section(s) capacity is sufficient.

The revolving speed of the torrefaction section channel screw transporter in combination with the axial temperature distribution may especially determine the temperature-time history of the particles in the torrefaction process.

The good heat transfer, along with the thermal inertia of the torrefaction section channel, may make the apparatus very stable against varying properties of the input and therewith secures the quality of the product of the system.

The torrefaction gas (torrefaction section off-gas) may exit the torrefaction section channel through a number of vents, for instance at a temperature of about 240 °C, which for straw and hay are seen as the optimum temperatures. It has been found that the system does not pollute with condensing heavy hydrocarbons which, most likely, is due to the selected combination of process temperatures (and temperature gradients inside the torrefaction section channel).

The torrefaction section may thus especially be configured to perform the biomass torrefying process at a temperature in the range of 200-300 °C (to produce torrefied biomass and off-gas)

Downstream of the torrefaction section, a cooling section may be arranged. The cooling section may simply be a receiver, wherein the torrefied biomass is received and allowed to cool. For instance, the receiver may be a batch receiver. In a specific embodiment however, the cooling section is configured analogues to the upstream arranged drying sections and torrefaction section. Hence, in an embodiment, it may be a screw in tube type unit, for instance from the outside cooled by water. The heat released may be considered as a loss. Preferably, the torrefied biomass in the cooling section is shielded from oxygen as long as it not at ambient temperature. One reason is to prevent leakage of air into the torrefaction section and another reason may be that the output can contain hot and pyrophoric particles, even if the bulk is well below 50 °C.

Further embodiments of the cooling section are describe above, and especially relate to the full-blade embodiment and the cylindrically shape of at least part of the cooling section channel.

Downstream of the torrefying section, and when a separate cooling section is available, downstream of the cooling section, a pelletizing section may be arranged. Again, a lock as defined above may be applied, now between the torrefying section and the cooling section, or if applicable, the cooling section and the pelletizing section.

Hence, in the upstream parts biomass has been cut into pieces, dried and torrefied, and may have been reduced in bulk density by for instance more than a factor 10, is transported to the pelletizing, especially via the above indicated lock.

The pelletizing section may comprise a pelletizer, configured to pelletize the (cooled) torrefied biomass.

The torrefied and cooled biomass may easily be pulverized to the size at which the pelletizer operates at lowest energy. Pelletizing requires less energy input when the material is at a higher temperature. It should be kept in mind, however, that the pelletising operation may increase the temperature. This means that upon cooling the temperature reduces more than the increase during pelletising. It is seen that these latter steps of some post grinding and pelletising may take less than 2% of the calorific value of the biomass. This may be a clear additional advantage of this process in comparison to only grinding and pelletising of the same feed stocks.

Further, the apparatus may allow the use of the input section of a standard pelletizer as the gas tight lock to prevent in-leak of air into the (upstream part of the) apparatus.

Hence, the apparatus according to the invention may further comprise a pelletizing section, arranged downstream of the cooling section, and configured to pelletize product emanating from the cooling section.

The process of the invention may especially (further) comprise pelletizing the cooled torrefied biomass to provide pelletized torrefied biomass wherein at least 80 wt.% have dimensions in the range of 0.1- mm – 10 cm. This may thus be performed in the pelletizing section.

The torrefaction section off-gas combustor may be able to combust for instance propane, natural gas and torrefaction gas as well as combinations of two or more of these. The propane and/or natural gas is for the start-up which involves heating up of parts of the apparatus, such as the torrefying zone and (via the torrefying zone also) the drying zones. When heated up and the torrefaction gas is starting to be produced, the propane and/or natural gas may gradually be replaced by the gas supplied in the basic process. The torrefaction gas may be led to the combustor through a (straight) pipe from the torrefying section.

Hence, in a specific embodiment, the torrefaction section off-gas combustor comprises a first burner, configured to burn at least part of the off-gas of the torrefaction section, and a auxiliary burner. This auxiliary burner (or start-up burner) can be used to start the system, and the fist burner takes over when the process is running. For instance, in an embodiment, the gas flows though a circular support burner to ignite the low LHV gas and to support the combustion process if the combustion properties of the torrefaction gas fluctuate. The final design of the off-gas combustor may be made in such a way that it can serve both start-up heating and heat supply during stationary operation.

Although not expected, fouling of the torrefaction burner (the first burner) can occur. Therefore the design may be made in such a way that a ground plate contains all the burners and a central dome gives space to the reaction and mixing in zones of gases. In a specific embodiment, the off-gas combustor comprises a central section with the first burner, an at least partly circumferentially arranged section with the auxiliary burner and a mutual exit section. Further, it may be beneficial when the off-gas combustor comprises an inlet for torrefaction section off-gas upstream of the first burner. In this way, the fuel for the first burner comes from beneath, which may reduce or prevent fouling.

The torrefaction section off-gas will be, if no or little gas from the dryer leaks into the reactor, of sufficient heating value such that the temperature rise during combustion (up to for instance more than 900 °C) is enough to break down all organic compounds in the gas. In this way, no gases will have to be post treated before release to the environment. The combustion temperature may, however, be too high to directly transfer it as thermal energy to for instance the torrefaction section, such as to the labyrinth heat exchangers. Hence, cold gas may be mixed in, for instance from the dryers, or air.

Especially, the (water containing) gas from the high-temperature drying section may be mixed in. Therefore, the flow of the contact air through the high-temperature drying section will be chosen in such a way that the inlet temperature of the gas to the heat exchanger of the reactor may especially be 400 °C, or slightly above. The total system of gas exiting from and feeding to the combustor may be controlled by for instance ventilators. Combustion air of the start-up burner may in an embodiment be supplied by a small ventilator which only operates during heating up.

In a further aspect, the invention also provides the gas combustor per se, especially in combination with the inlet for a combustible gas, such as the torrefaction section off-gas upstream, of the first burner. In such embodiment, the gas combustor may be applied to combust any gas, especially those with combustible aerosol particles (like torrefaction section off-gas).

The thermal energy generated in the combustor (of the torrefaction section off-gas) can be reintroduced in the system. This may especially be done by guiding the hot gas of the combustor to the sections in need of thermal energy, such as the torrefaction section, and the drying sections. In a specific embodiment, this may be performed in a sequential way, i.e. at least part of the thermal energy is first transferred to the torrefaction section, and thermal energy is then subsequently transferred to the drying sections. Optionally, also other transfer routes may be chosen, but the specific embodiment one (mentioned above) may be most efficient. For transfer of thermal energy, a thermal energy transfer system is used. The thermal energy generated in the combustor can also reintroduced in the system via a fluid (such as a gas), in heat exchange with the combustor.

Hence, at least part of the thermal energy may be transferred from the combustion process to the torrefying process, and at least part of the remaining thermal energy may be transferred from the torrefying process to the low-temperature drying process and high-temperature drying process.

In a specific embodiment, the thermal energy transfer system comprises a gas transport system and a gas transporter, wherein the gas transport system comprises a first gas connection between the torrefaction section off-gas combustor and a torrefaction channel heat exchanger of the torrefaction channel, a second gas connection between the torrefaction channel heat exchanger and the low-temperature drying section and a third gas connection between the torrefaction channel heat exchanger and the high-temperature drying section. The channel heat exchangers may be heat exchangers attached to the wall(s) of the channels, for instance within mantles. However, mantles themselves, through which hot gasses may be transported, may also be considered heat exchangers per se.

The gas transporter may for instance comprise a blower, a ventilator or a pump. In an embodiment, the gas transporter may also comprise a plurality of (such) gas transporters. In principle, the gas transport in the complete system can be realized with one central transporter comprising for instance a blower, ventilator or pump. As gas has to be blown at different temperatures, it can however be more economical to apply a number (in general not more than three) of separate transporters, such as blowers, operating at lower capacity than in the case of one.

In a specific embodiment, the gas transporter may be arranged downstream of the torrefaction channel heat exchanger and upstream of the low-temperature drying section and the high-temperature drying section, and the gas transport system may further comprises a conditioning gas inlet. The conditioning gas may be used to reduce the temperature of the gas.

Especially, the second gas connection between the torrefaction channel heat exchanger and the low-temperature drying section connects the torrefaction channel heat exchanger and (a) a low-temperature drying section channel heat exchanger and (b) the low-temperature drying section channel, and the third gas connection between the torrefaction channel heat exchanger and the high-temperature drying section connects the (c) torrefaction channel heat exchanger and (d) a high-temperature drying section channel heat exchanger and the high-temperature drying section channel. In this way, direct heating (by a drying gas) and indirect heating in the drying sections may be applied.

The design of the apparatus may be made in such a way that one main gas transporter may be placed between the heat exchanger(s) of the torrefying section and the input side of the drying sections (see also above). In this way, it may take care of the input of torrefaction gas out of the torrefying zone, its supply of combustion air and flow of quench gas (conditioning gas) input from the drying sections at the upstream side. Therefore, the upstream side of the apparatus may operate at under pressure. At the downstream side it delivers the hot gas to the high-temperature and low-temperature dryers.

As indicated above, conditioning gas, such as air, may be necessary to be fed in to reduce the temperature of the gas delivered to the transporter, not only to keep its operation temperature within limits, but also to prevent overheating of the drying sections. If this latter occurs, the release of hydrocarbons in the high-temperature drying section might become too high and even the torrefaction process might start already there.

As already indicated above for some embodiments, the apparatus may comprise a low-temperature dryer comprising the low-temperature drying section, a high-temperature dryer comprising the high-temperature drying section, a torrefaction unit (or reactor) comprising the torrefaction section, and a cooler comprising the cooling section. In addition, the apparatus may comprise the grinder (upstream of the low-temperature dryer), and the cooler (downstream of the torrefaction unit), and a pelletizer unit (comprising the pelletizing section with pelletizer), downstream of the cooler.

Especially preferred parameters are indicated below in the tables. The tables give all kind of preferred ranges, of which one or more or all may be selected when using the apparatus and/or applying the process of the invention.

Table 1: Characteristics of the heating system. For temperatures and flows operational ranges are given. Values in bold give best performance of the system.

Type	Dual burner, high capacity for starting up, support burner for torrefaction gas combustion		
	Power output (kW)	Gas flow (kg/hour)	LHV gas MJ/kg; MJ/Nm^3
Start up burner capacity	200	19	74; 33
Support burner capacity	0.5-10 **3**	0.02-10 **5**	74; 33
Torrefaction gas input capacity	270-290 **280**	220-280 **260**	4.5; 4.5
Combustion air input		390-400	
	Input gas temperature	Gas flow	Output gas temperature
Quench gas	110	1950-2850 **2360**	
Output or flue gas temperature		2570-3475 **2980**	400-440 **400**

Table 2: Characteristics of the main components of the system. For temperatures and flows operational ranges are given. Values in bold give best performance of the system

	Torrefaction unit	High-temperature dryer	Low-temperature dryer	Cooling unit
type	Screw in	Screw in tube	Screw in tube	Screw in

	Torrefaction unit	High-temperature dryer	Low-temperature dryer	Cooling unit
	trough			tube
Inner diameter (m)	0.60	0.70	0.70	0.50
Outer diameter (m)	0.75	0.85	0.85	0.60
Length (m)	6.0	6.0	6.0	6.0
Axial transport speed (m/min)	>0.2; <1.0	>0.2; <1.0	>0.2; <1.0	>0.2; <1.0
Heat transfer	Mantle	Mantle and contact	Mantle and contact	Mantle
Inlet temperature Contact gas (°C)		160-220 **170**	145-200 **145**	
Inlet temperature Mantle gas (°C)	400-440C **440**	220-170 **170**	145-200 **145**	15 (water)
Outlet temperature Contact gas (°C)	240 **240**	110-60 **110**	65-85 **65**	
Outlet temperature Mantle gas (°C)	350-380 **375**	110-60 **110**	65-90 **65**	40 (water)
Inlet temperature product (°C)	140-140 **130**	110 **110**	20 **20**	230
Outlet temperature product (°C)	230-230 **230**	130-140 **140**	110-115 **115**	70
Gas flows contact (kg/hour)	220-240 **220**	1500-3900 **1950**	650-2850 **2150**	
Gas flow mantle (kg/hour)	2500-5100 **2500**	1500-1900 **1880**	1110-11150 **2150**	2000 (water)

The best performances may depend upon the chosen dimensions of the apparatus.

The invention also provides a product, obtainable by the process of the invention. Especially, the invention provides a torrefied product (end product), obtainable by the process invention, having a water content in the range of 2-10 wt.%, preferably 5-10 wt.%. Further, a pelletized torrefied biomass (end product) may be provided at least 80 wt.% of the pellets have dimensions in the range of 0.1- mm – 10 cm. Pelletizing may include providing briquettes. For instance, pellets may be provided having a diameter in the range of 4-10 mm and a diameter in the range of 1-7 cm.

Table 3 shows the properties of the pellets which may be produced with the apparatus. They compare well with other specifications. Due to the specific origin of the input, the potassium content is relatively high. The product has good durability, little or no uptake of moist during storage and good combustion properties. It must be mentioned in this respect; however, that the material has high density and therefore needs residence time and sufficient temperature during combustion of it is not grinded. Standard house-hold saw dust pellet burners will need modifications to use this quality as a fuel.

The material is very well suited for co-combustion on large coal and co-generation plants.

Table 3: pellet characteristics

Requirements for Pellets					Pellet
Characteristics	Unit	NORM M 7135	DIN 51 731	DIN plus	Straw-based
Diameter D	mm	4 ≤ D < 10	5 ≤ D < 10	-	D < 6
Length	mm	≤ 5 x D	< 50	< 5 x d	< 50
Gross density	kg/dm³	≥ 1,12	> 1,0 - 1,4	> 1,12	>1,2
Water content	%	≤ 10	< 12	< 10	<5%
Abrasion	%	≤ 2,3	-	≤ 2,3	<0,1
Ash content	%	≤ 0,5	< 1,5	< 0,5	<3,9%
Net calorific value (LHV)	MJ/kg	≥ 18	17,5 - 19, 5	> 18	>18<21
Sulphur content	%	≤ 0,04	< 0,8	< 0,4	<0,18
Nitrogen content	%	≤ 0,30	< 0,30	< 0,30	<0,18
Chlorine content	%	≤ 0,02	< 0,03	< 0,02	<0,01
Halogenated compounds	-	-	-	-	<0,5%
Resins	mg/kg	-	< 0,8	< 0,8	0%
Lead	mg/kg	-	< 10	< 10	<1
Cadmium	mg/kg	-	< 0,5	< 0,5	<1
Chromium	mg/kg	-	< 8	< 8	<6
Copper	mg/kg	-	< 5	< 5	<6
Mercury	mg/kg	-	< 0,05	< 0,05	<0,1

Requirements for Pellets					Pellet
Zinc	mg/kg	-	< 100	< 100	<30
Added adhesives	%	≤ 2	not allowed	≤ 2	0

The terms “upstream” and “downstream” relate to an arrangement of items or features relative to the propagation of the biomass, from the first entrance in the apparatus (here the especially the low-temperature drying section or grinding section, respectively), wherein relative to a first position within a flow of biomass from the entrance of the biomass in the apparatus, a second position in the apparatus/flow closer to first entrance is “upstream”, and a third position within the apparatus/flow further away from the first entrance is “downstream”.

The term “substantially” herein, such as in “substantially consists”, will be understood by the person skilled in the art. The term “substantially” may also include embodiments with “entirely”, “completely”, “all”, etc. Hence, in embodiments the adjective substantially may also be removed. Where applicable, the term “substantially” may also relate to 90% or higher, such as 95% or higher, especially 99% or higher, even more especially 99.5% or higher, including 100%. The term “comprise” includes also embodiments wherein the term “comprises” means “consists of”.

Furthermore, the terms first, second, third and the like in the description and in the claims, are used for distinguishing between similar elements and not necessarily for describing a sequential or chronological order. It is to be understood that the terms so used are interchangeable under appropriate circumstances and that the embodiments of the invention described herein are capable of operation in other sequences than described or illustrated herein.

The apparatus herein are amongst others described during operation. As will be clear to the person skilled in the art, the invention is not limited to methods of operation or devices in operation.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. Use of the verb "to comprise" and its conjugations does not exclude the presence of elements or steps other than those stated in a claim. The article "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The invention may be implemented by means of hardware comprising several distinct elements, and by means of a suitably programmed computer. In the device or apparatus claims enumerating several means, several of these means may be embodied by one and the same item of hardware. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

The invention further applies to an apparatus comprising one or more of the characterising features described in the description and/or shown in the attached drawings. The invention further pertains to a process comprising one or more of the characterising features described in the description and/or shown in the attached drawings.

In a specific embodiment, the torrefaction channel is U-shaped and the torrefaction section channel screw transporter comprises a ribbon blade screw transporter.

In a specific embodiment, the cooling section channel is cylindrically shaped and the cooling section channel screw transporter comprises a full blade screw transporter.

In a specific embodiment, the low-temperature drying section and the high-temperature drying section channels are U-shaped or cylindrically shaped or comprise one or more U-shaped sections and one or more cylindrically shaped sections. The screw transporters in these channels comprise in these embodiments for instance independently full blade screw transporter(s) or ribbon blade screw transporters.

The various aspects discussed in this patent can be combined in order to provide additional advantages. Furthermore, some of the features can form the basis for one or more divisional applications.

Brief description of the drawings

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts, and in which:

Figure 1 schematically depicts an a simplified scheme of the apparatus (or process);

Figure 2 schematically depicts a more detailed embodiment of the apparatus (or process);

Figure 3 schematically depicts another embodiment of the apparatus of the invention;

Figures 4a-4f schematically depict some variants on channels and/or screw transporters;

Figures 5a and 5b schematically depict an embodiment of a lock and the off-gas combustor, respectively.

Description of preferred embodiments

Figure 1 schematically depicts an apparatus 1 for the thermal treatment of biomass 10. The apparatus comprises a low-temperature drying section 100, a high-temperature drying section 200, a torrefaction section 300 and an optional cooling section 400. Biomass 10 is transported through the apparatus 1 from the low-temperature drying section 100, subsequently to the high-temperature drying section 200, subsequently to the torrefaction section 300 and subsequently to the cooling section 400. The high-temperature drying section 200 is arranged downstream of the low-temperature drying section 100, the torrefaction section 300 is arranged downstream of the high-temperature drying section 200, and the cooling section 400is arranged downstream of the torrefaction section 300.

Biomass transport from the low-temperature cooling section 100 to the high temperature cooling section 200 is indicated with reference 150. Transport of dried biomass from the latter section to the torrefaction section 300 is indicated with reference 250. Transport of torrefied biomass from the latter section to the cooling section is indicated with reference 350. Torrefied biomass is indicated with reference 20. Torrefied biomass may be cooled and may be pelletized (see also below).

The apparatus 1 further comprises a torrefaction section off-gas combustor 500. Transport of off-gas from the torrefaction section 300 to the off-gas combustor 500 is indicated with reference 360. The combustion of the off-gas 360 in the off-gas combustor 500 generates thermal energy. This thermal energy may be used to heat the low-temperature drying section 100, the high-temperature drying section 200, and the torrefaction section 300. To this end, the apparatus 1 further comprises a thermal energy transfer system 600, which may be in thermal contact with the torrefaction section off-gas combustor 500 (to receive the thermal energy), indicated with reference 605 (thermal connection), and for delivering thermal energy, with the torrefaction section 300, the high-temperature drying section 200 and the low-temperature drying section 100, which is indicated with references 603, 602 and 601 (thermal connections), respectively.

Figure 2 schematically depicts in more detail a specific embodiment of the apparatus 1 according to the invention. References 101, 201, 301 and 401, respectively, refer to heat exchangers with the walls of the respective sections. For instance, a mantle may be used, through which (hot) gas may be fed, which heats the specific section. For instance, referring to section 100, reference 101 may be a section mantle, through which hot gas is lead.

Hot gas originally originating from the combustor 500 may be finally fed in a mantle, here indicated with reference 101, (indirect heating), of the low-temperature drying section 100, but may also be introduced in the low-temperature drying section 100 itself (direct heating). This is indicated with references 62b and 62a (drying gas), respectively, which refer to gas connections.

Likewise, hot gas originally originating from the combustor 500 may be finally fed in a mantle, here indicated with reference 201, (indirect heating), of the high-temperature drying section 200, but may also be introduced in the high-temperature drying section 200 itself (direct heating). This is indicated with references 613b and 613a (drying gas), respectively, which refer to gas connections.

In general, hot gas originally originating from the combustor 500 may be fed in the mantle, here indicated with reference 301, (indirect heating), of the torrefaction section 300. This is indicated with references 611, which indicates a gas connection.

As shown, hot gas from the off-gas combustor 500 may in this embodiment first be transported (gas connection 611) to the heat exchanger of or mantle 301 of the torrefaction section, whereafter from this heat exchanger or mantle 301, hot gas (but reduced in temperature) will be transported (gas connection 612) to the low-temperature section 100 and high-temperature section 200. In an embodiment, the hot gas from the torrefaction section 300 is split in two gas connections, here indicated with reference 614, splitting in two gas connections 612 and 613.

Hence, the thermal energy transfer system 600 may include a gas transport system 610, of which an embodiment is schematically depicted in figure 2. Here, in this embodiment, the gas transport system further comprises a gas transporter 620, such as a blower, ventilator or pump, which may be responsible for all gas flow (for heating) from the off-gas combustor 500 to the low-temperature drying section 100, the high-temperature drying section 200 and the torrefaction section 300. Optionally, to control the temperature of the gas (for thermal energy transfer) after the torrefaction section 300, the gas transport system 610 may further comprise a conditioning gas inlet 631, for instance for letting air into the gas transport system 610. Reference 630 refers to a mixing point, for mixing the hot heating gas from the heat exchanger or mantle 301 of the torrefaction section 300 and the conditioning gas. Reference 640 indicates another optional mixing point, wherein hot drying gas from the heat exchanger or mantle 201 of the high temperature drying section 201 may be combined into the gas connection 612 for heating the low-temperature drying section 100.

Hence, figure 2 also shows that the gas transport system comprises (I) first gas connection 611 between (on the one hand) the torrefaction section off-gas combustor 500 and (on the other hand) (a) the torrefaction channel heat exchanger 301 of the torrefaction channel 310, (II) second gas connection 612 between (on the one hand) the torrefaction channel heat exchanger 301 and (on the other hand) (a) the low-temperature drying section 100, and (III) third gas connection 613 between (on the one hand) the torrefaction channel heat exchanger 301 and (on the other hand) (a) the high-temperature drying section 200.

Especially, the second gas connection 612 between the torrefaction channel heat exchanger 301 and the low-temperature drying section 100 connects (on the one hand) the torrefaction channel heat exchanger 301 and (on the other hand) (a) the low-temperature drying section channel heat exchanger 101 and (b) the low-temperature drying section channel 110. Further, especially the third gas connection 613 between the torrefaction channel heat exchanger 301 and the high-temperature drying section 200 connects (on the one hand) the torrefaction channel heat exchanger 301 and (on the other hand) (a) the high-temperature drying section channel heat exchanger 201 and (b) the high-temperature drying section channel 210.

Up to now, it is generally spoken about sections. However, as will be clear to the person skilled in the art, especially also separate reactors may be applied. Hence, figure

2 also depicts the variant wherein the apparatus 1 comprises a low-temperature dryer 1100 comprising the low-temperature drying section 100, a high-temperature dryer 1200 comprising the high-temperature drying section 200, a torrefaction unit 1300 comprising the torrefaction section 300, and a cooler 1400 comprising the cooling section 400.

The cooling section 400 may be cooled by exposing the heat exchanger or mantle 401 to air and/or to water, preferably at ambient temperature of the air and/or water, or at lower temperatures than ambient.

Figure 3 schematically depicts an embodiment of how the apparatus 1 could be arranged. By way of example, now also a grinding section 700, arranged upstream of the low-temperature drying section 100 is depicted. As will be clear to the person skilled in the art, such grinding section 700 may also be included in the apparatus 1 schematically depicted in figures 1 and 2. For instance a grinder 1700 may be applied, which comprises the grinding section. As example, the grinding section 700 (and thus the grinder 1700) may comprise a fast rotating drum.

Further, by way of example, now also a pelletizing section 800, arranged downstream of the cooling section and configured to pelletize the product 20 emanating from the cooling section 400 is depicted. A pelletizing unit, such as a grinder, comprising such pelletizing section 800 is indicated with reference 1800. As will be clear to the person skilled in the art, such pelletizing section 800 may also be included in the apparatus 1 schematically depicted in figures 1 and 2. For instance, the pelletizing section 800 (and thus the pelletizing unit 1800) may comprise a pelletizer device configured to provide pellets having dimensions in the range of 0.1- mm – 10 cm. The thermal energy transfer system may be integrated in the apparatus, and is here not made explicitly visible. A closure 849 may be used to close a transportation channel for the torrefied biomass from the torrefying section 400 to the pelletizing section 800.

Figures 4a-4c schematically depicts embodiments of the channel sections and screw transporters. These schematic drawings may apply to all sections, section channels and section channel screw transporters, and are therefore indicated with 100, 200, 300, 400, and 110, 210, 310, 410, and 120, 220, 320 and 420, respectively. Figure 4b schematically depicts a U-shaped section channel or section channel part. Figure 4c schematically depicts a circularly shaped section channel or section channel part. As indicated above, the channels may have parts that are circularly shaped and parts that are U-shaped.

Figures 4d-4f schematically depict a non-limiting number of screw transporters or screw conveyers. Again, the depicted screw transporters may be used in any section, and are therefore indicated with reference, 120, 220, 320, 420. Figure 4d schematically depicts a full blade screw transporter FB. Figure 4e schematically depicts a ribbon bladed screw transporter RB and figure 4f schematically depicts a variant with screw transporter with blade extensions BE. By way of example, they are configured to be parallel with the screw axis (indicated with reference SA).

Figure 5a schematically depicts an embodiment of a lock 260, which may for instance be arranged downstream of the high-temperature drying section 200 and upstream of the torrefaction section 300. The lock comprises 260 at least two oppositely arranged rotators 261 with a non-zero distance d to each other. The lock 260 may especially configured, in this arrangement of items, to transport dried biomass 250 from the high-temperature drying section 200 to the torrefaction section 300. Further, the lock 260 may, in this way also, be configured to inhibit gas flow from one section to the other. The rotators 261 rotate oppositely of each other. In an embodiment (not depicted) a plurality of oppositely arranged adjacent rotators 261 may be used

Figure 5b schematically depicts an embodiment of the off-gas combustor 500. In the schematically depicted embodiment, the torrefaction section off-gas combustor 500 comprises a first burner 561, configured to burn at least part of the off-gas 360 of the torrefaction section 300, and an auxiliary burner 531 (here, by way of example, two of such auxiliary burner(s) 531 are depicted in this cross-section). Especially, the off-gas combustor 500 may comprise a central section 532 with the first burner 561. This central section may at least partly be circumfered by a circumferential section 520 with the auxiliary burner(s) 531. Further, the off-gas combustor 500 may comprise a mutual exit section 533, mutual for the central section 532 and circumferential section 520.

Figure 5b also schematically shows that the off-gas combustor 500 comprises an inlet 562 for torrefaction section off-gas 360 upstream of the first burner 531. In this way, torrefaction section off-gas 360 flows from below to above. Thereby fouling of the first burner 531 may be diminished or even be prevented.

The off-gas combustor 500 may comprise a further inlet 40, through which off-gas of the high-temperature drying section 200 may be introduced in the off-gas combustor 500. Compounds in that gas that should not be released in the air are combusted in the off-gas combustor. Further, this gas may also be used to control the combustor temperature (“quench gas”). The gas connection between the high-temperature dryer 200 and off-gas combustor is indicated with reference 650.

Hence, the invention may provide a high throughput trough like torrefaction reactor with high thermal stability giving the possibility to yield the highest possible heating value off gas which allows the system to be run auto thermally.

Further, the invention may provide a combustor equipped with two burners that combust the torrefaction gas at high enough temperature to destroy all environmentally hazardous organic components with a simple strategy to control the complete process, and a high capacity start up burner for heating up the complete system to operation condition. Although not expected, fouling of transfer lines is accepted as a possibility and precautions are taken to clean the system without disruption continuous operation.

Further, the apparatus can be run with only one standard blower located between reactor and dryers. Gas valves control the heat flows in the various sections but do not need active control during stable operation even if the properties of the input varies.

In order to guarantee highest possible calorific value off gas from the torrefying section, a mechanical separation unit may be placed between the high-temperature drying section output and the torrefying section input. On top of this the apparatus allows for in-leak suppression by adjusting the gas pressure in the high-temperature drying section and the torrefying section without influencing the quality of the product and the off gas.

A further measure to suppress in leak of air into the torrefying section may be obtained by integrating the pelletizer into the system. The temperature of the output material is readily chosen in such a way that best performance of the pelletizer with lowest electricity demand is possible.

The invention provides splitting up of the drying sections into a high and low-temperature section due to the peculiarities of the moist release of the input. Gas streams and way of heat input can be chosen in such a way that the emission of the apparatus is clean air and pure water.

Claims

1. An apparatus (1) for the thermal treatment of biomass (10), comprising:
    - a low-temperature drying section (100) comprising a low-temperature drying section channel (110) with low-temperature drying section channel screw transporter (120);
    - a high-temperature drying section (200) comprising a high-temperature drying section channel (210) with high-temperature drying section channel screw transporter (220);
    - a torrefaction section (300) comprising a torrefaction channel (310) with torrefaction section channel screw transporter (320);
    - a cooling section (400) comprising a cooling section channel (410) with cooling section channel transporter (420), preferably a cooling section channel screw transporter;
    - a torrefaction section off-gas combustor (500);
    - a thermal energy transfer system (600), in thermal contact with the torrefaction section off-gas combustor (500), the torrefaction section (300), the high-temperature drying section (200) and the low-temperature drying section (100).
2. The apparatus (1) according to claim 1, wherein the low-temperature drying section channel screw transporter (120) and the high-temperature drying section channel screw transporter (220) are independently selected from the group consisting of a full blade screw transporter, a ribbon blade screw transporter and a perforated blade screw transporter.
3. The apparatus (1) according to any one of the preceding claims, wherein the torrefaction screw transporter (320) is a ribbon blade screw transporter, optionally equipped with blade extensions.
4. The apparatus (1) according to any one of the preceding claims, wherein the cooling section channel transporter (420) is a full screw blade transporter.
5. The apparatus (1) according to any one of the preceding claims, wherein one or more of at least part the low-temperature drying section channel (110), at least part of the high-temperature drying section channel (210) and at least part of the torrefaction section channel (310) are cylindrically shaped.

6. The apparatus (1) according to any one of the preceding claims, wherein one or more of at least part the low-temperature drying section channel (110), at least part of the high-temperature drying section channel (210) and at least part of the torrefaction section channel (310) are U-shaped.
7. The apparatus (1) according to claim 6, wherein further one or more of at least another part the low-temperature drying section channel (110), at least another part of the high-temperature drying section channel (210) and at least another part of the torrefaction section channel (310) are cylindrically shaped.
8. The apparatus (1) according to any one of the preceding claims, wherein the thermal energy transfer system (600) comprises a gas transport system (610) and a gas transporter (620), wherein the gas transport system comprises a first gas connection (611) between the torrefaction section off-gas combustor (500) and a torrefaction channel heat exchanger (301) of the torrefaction channel (310), a second gas connection (612) between the torrefaction channel heat exchanger (301) and the low-temperature drying section (100) and a third gas connection (613) between the torrefaction channel heat exchanger (301) and the high-temperature drying section (200).
9. The apparatus (1) according to claim 8, wherein the gas transporter (620) is arranged downstream of the torrefaction channel heat exchanger (301) and upstream of the low-temperature drying section (100) and the high-temperature drying section (200), wherein the gas transport system (610) further comprises a conditioning gas inlet (631), and wherein the gas transporter (620) comprises a blower, ventilator or pump.
10. The apparatus (1) according to any one of claims 8-9, wherein the second gas connection (612) between the torrefaction channel heat exchanger (301) and the low-temperature drying section (100) connects the torrefaction channel heat exchanger (301) and a low-temperature drying section channel heat exchanger (101) and the low-temperature drying section channel (110), and wherein the third gas connection (613) between the torrefaction channel heat exchanger (301) and the high-temperature drying section (200) connects the torrefaction channel heat exchanger (301) and a high-temperature drying section channel heat exchanger (201) and the high-temperature drying section channel (210).

11. The apparatus (1) according to any one of the preceding claims, comprising a low-temperature dryer (1100) comprising the low-temperature drying section (100), a high-temperature dryer (1200) comprising the high-temperature drying section (200), a torrefaction unit (1300) comprising the torrefaction section (300), and a cooler (1400) comprising the cooling section (400).
12. The apparatus (1) according to any one of the preceding claims, further comprising a grinding section (700), arranged upstream of the low-temperature drying section (100).
13. The apparatus (1) according to any one of the preceding claims, further comprising a lock (260) arranged downstream of the high-temperature drying section (200) and upstream of the torrefaction section (300), wherein the lock (260) comprises at least two oppositely arranged rotators (261) with a non-zero distance to each other, wherein the lock (260) is configured to transport dried biomass (250) from the high-temperature drying section (200) to the torrefaction section (300) and wherein the lock (260) is configured to inhibit gas flow from one section to the other.
14. The apparatus (1) according to any one of the preceding claims, further comprising a pelletizing section (800), arranged downstream of the cooling section, and configured to pelletize product emanating from the cooling section.
15. The apparatus (1) according to any one of the preceding claims, wherein the torrefaction section off-gas combustor (500) comprises a first burner (561), configured to burn at least part of the off-gas (360) of the torrefaction section (300), and a auxiliary burner (531).
16. The apparatus (1) according to claim 15, wherein the off-gas combustor (500) comprises a central section (532) with the first burner (561), an at least partly circumferentially arranged section (520) with the auxiliary burner (531) and a mutual exit section (533).
17. The apparatus (1) according to any one of claims 15-16, wherein the off-gas combustor (500) comprises an inlet (562) for torrefaction section off-gas (360) upstream of the first burner (531).
18. A process for the thermal treatment of biomass comprising
    - providing biomass;

- transporting the biomass through a low-temperature drying section, a high-temperature drying section, a torrefaction section and a cooling section, with one or more screw transporters; and
- drying in a low-temperature drying process the biomass at a temperature in the range of 90-120 °C in the low-temperature drying section;
- drying in a high-temperature drying process the biomass at a temperature in the range of 150-220 °C in the high-temperature drying section;
- torrefying in a torrefying process the biomass a temperature in the range of 200-300 °C in the torrefaction section to produce torrefied biomass and off-gas;
- cooling in a cooling process the torrefied biomass in the cooling section;
- combusting in a combustion process at least part of the off-gas to produce thermal energy;
- transferring at least part of the thermal energy to the low-temperature drying process, to the high-temperature drying process, and to the torrefying process.

19. The process according to claim 18, wherein the biomass comprises agricultural waste.
20. The process according to any one of claims 18-19, wherein the biomass comprises straw or hay.
21. The process according to any one of claims 18-20, wherein at least part of the thermal energy is transferred from the combustion process to the torrefying process, and wherein at least part of the remaining thermal energy is transferred from the torrefying process to the low-temperature drying process and high-temperature drying process.
22. The process according to any one of claims 18-21, further comprising grinding the biomass before subjecting to the low-temperature drying process.
23. The process according to any one of claims 18-22, further comprising pelletizing the cooled torrefied biomass to provide pelletized torrefied biomass wherein at least 80 wt.% have dimensions in the range of 0.1- mm – 10 cm.
24. The process according to any one of claims 18-23, wherein the biomass before the low-temperature drying process has a water content in the range of 5-25 wt.%, preferably 5-20 wt.%.

25. The process according to any one of claims 18-24, wherein the apparatus (1) according to any one of claims 1-17 is applied.
26. A torrefied product, obtainable by the process according to any one of claims 18-25, having a water content in the range of 2-10 wt.%, preferably 5-10 wt.%.

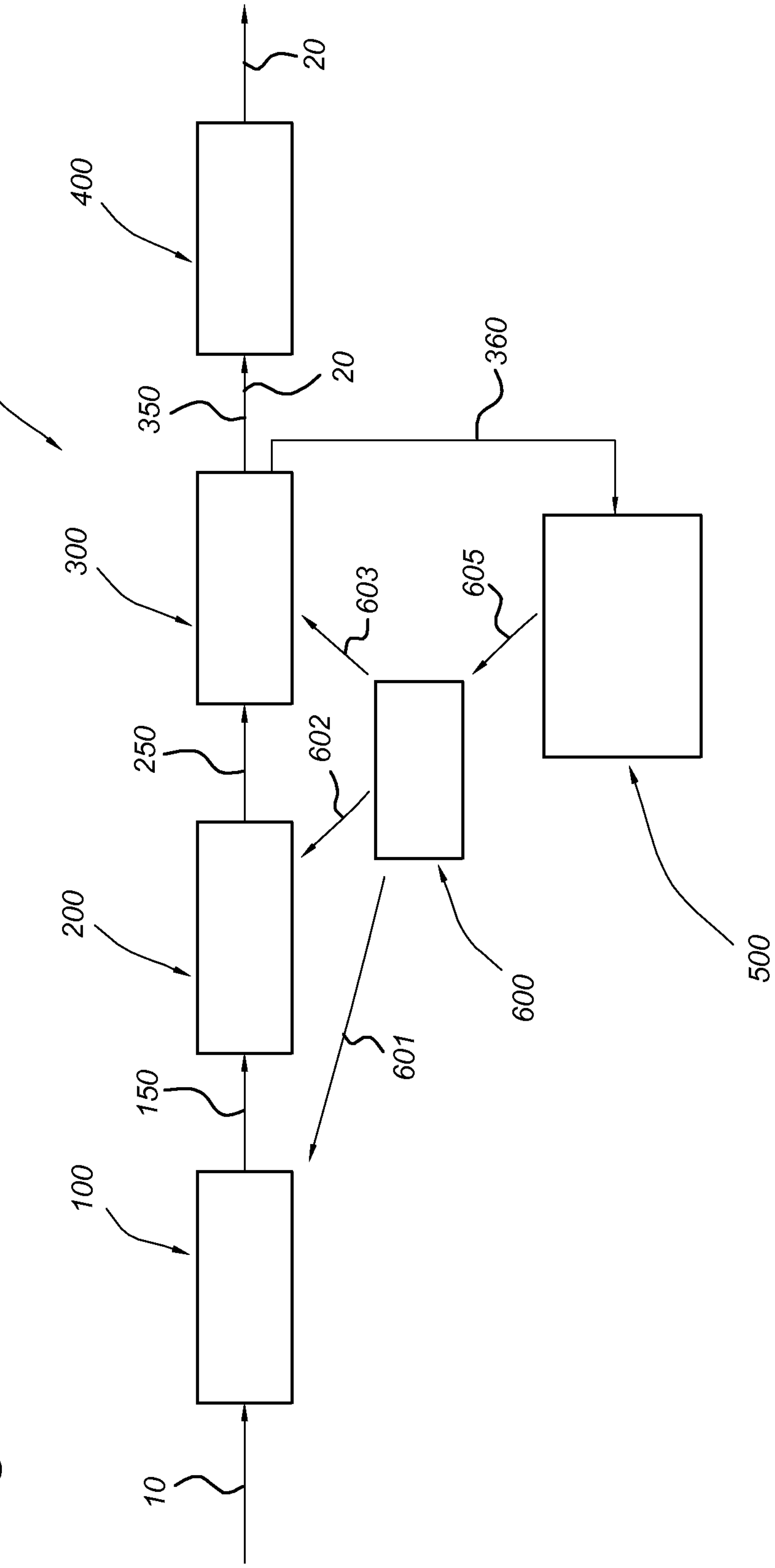

Fig 1

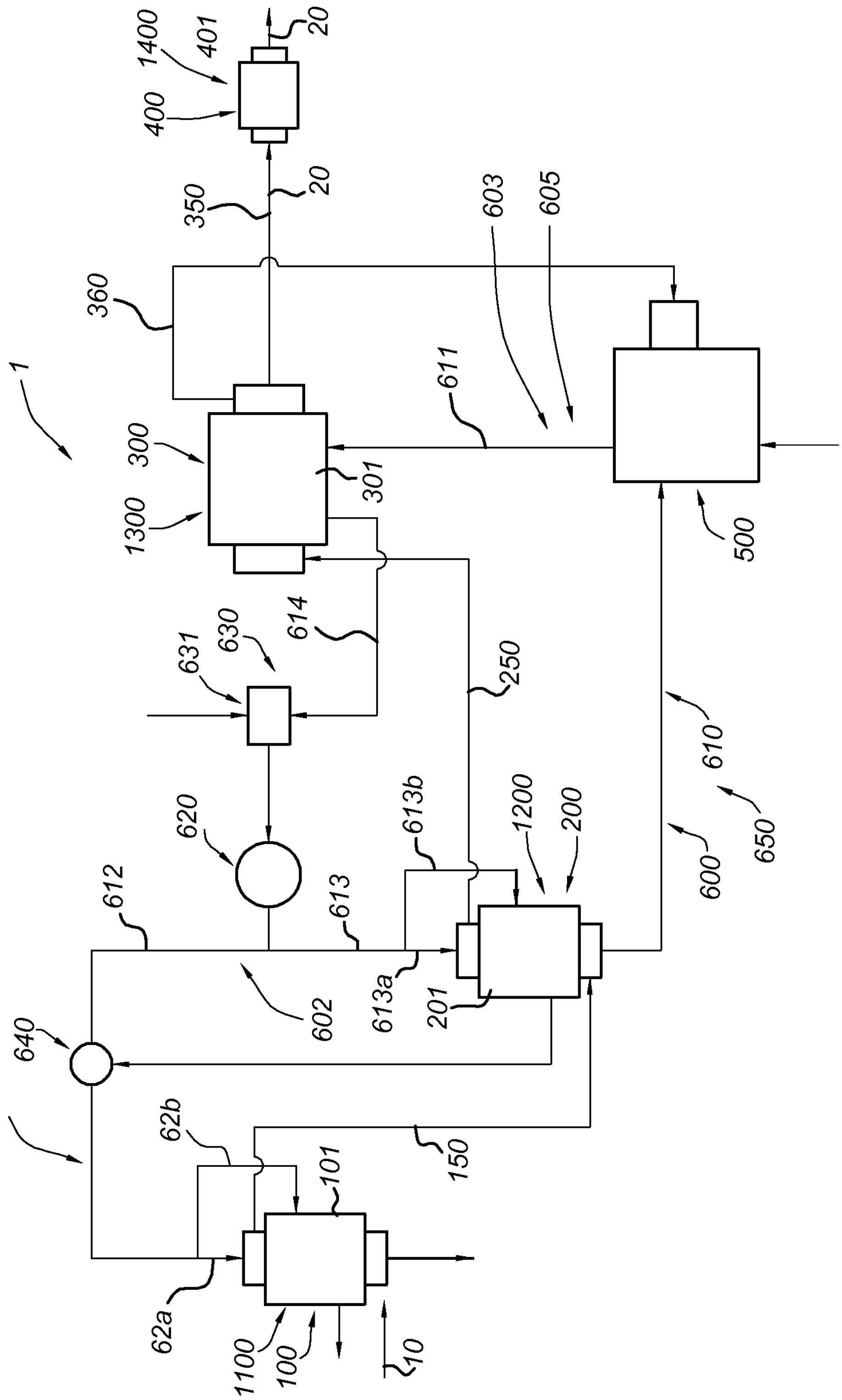
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Fig 2

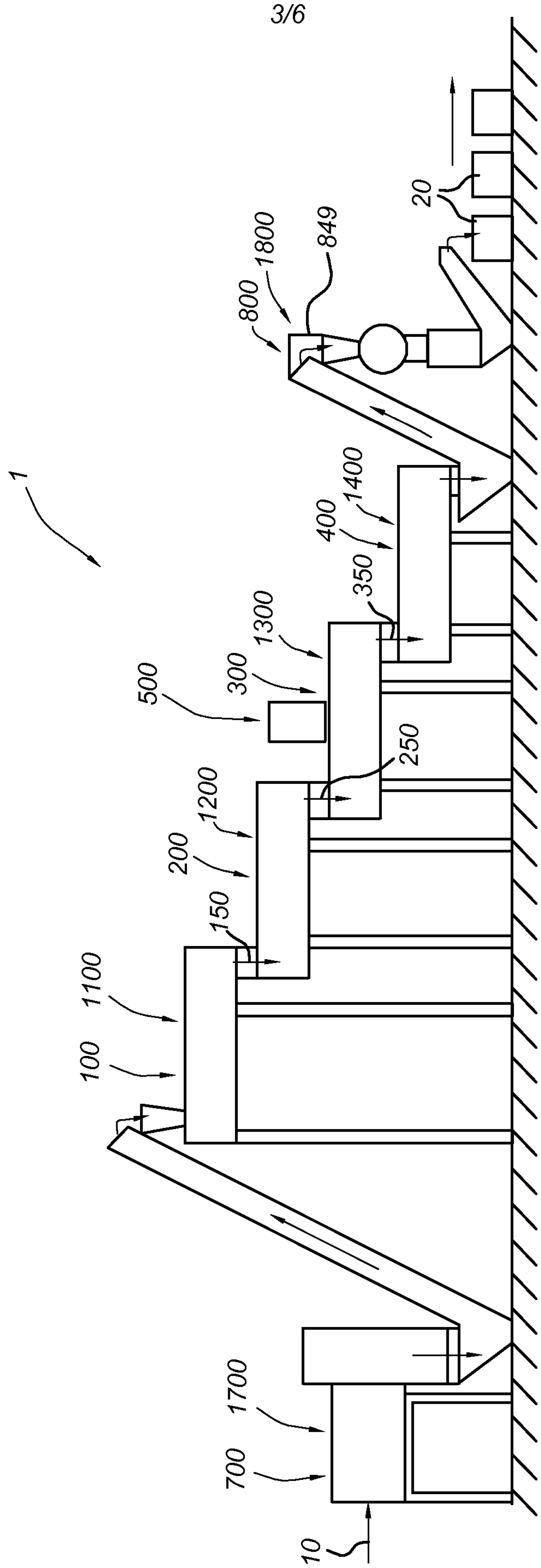
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Fig 3

Fig 4a

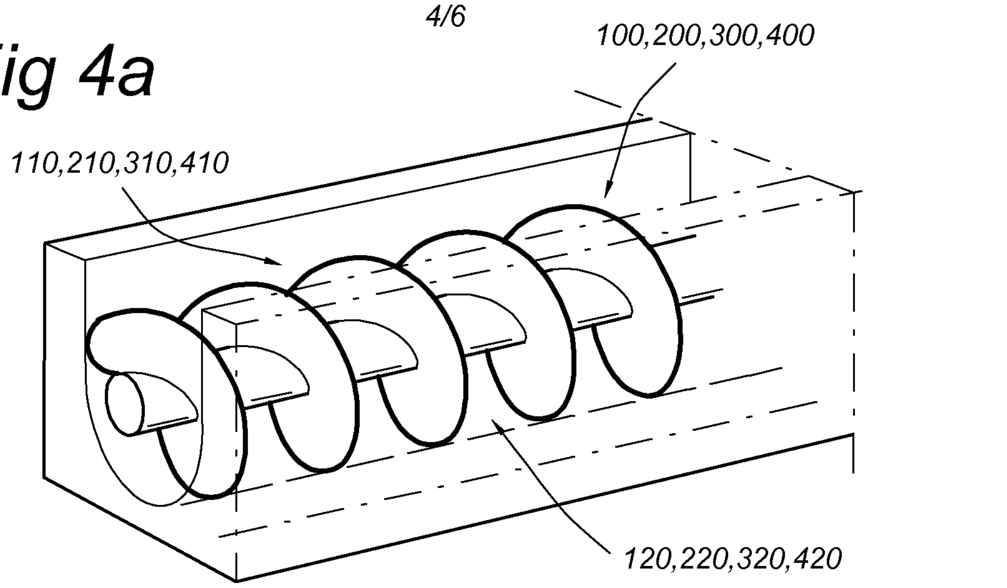

Fig 4b

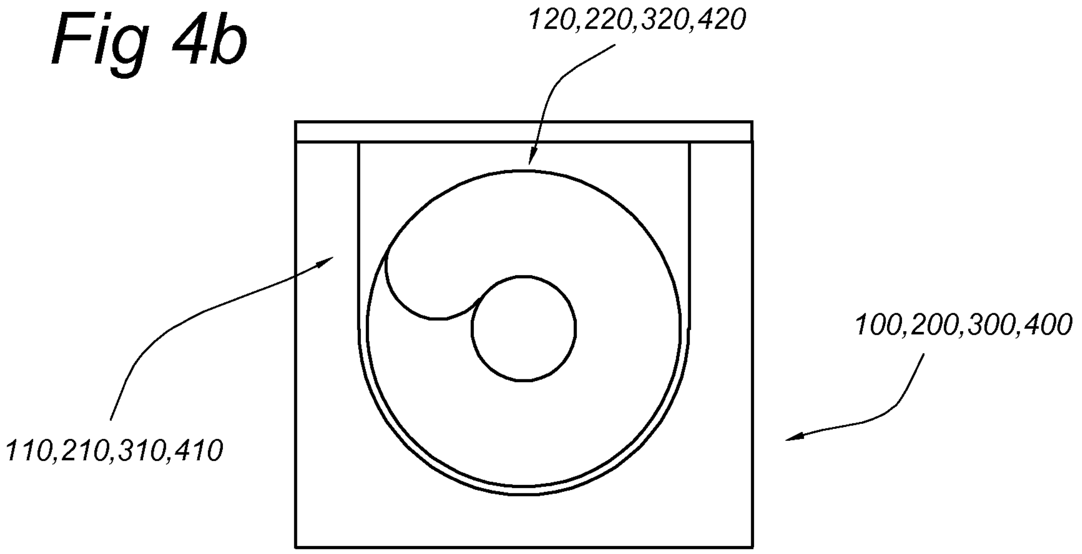

Fig 4c

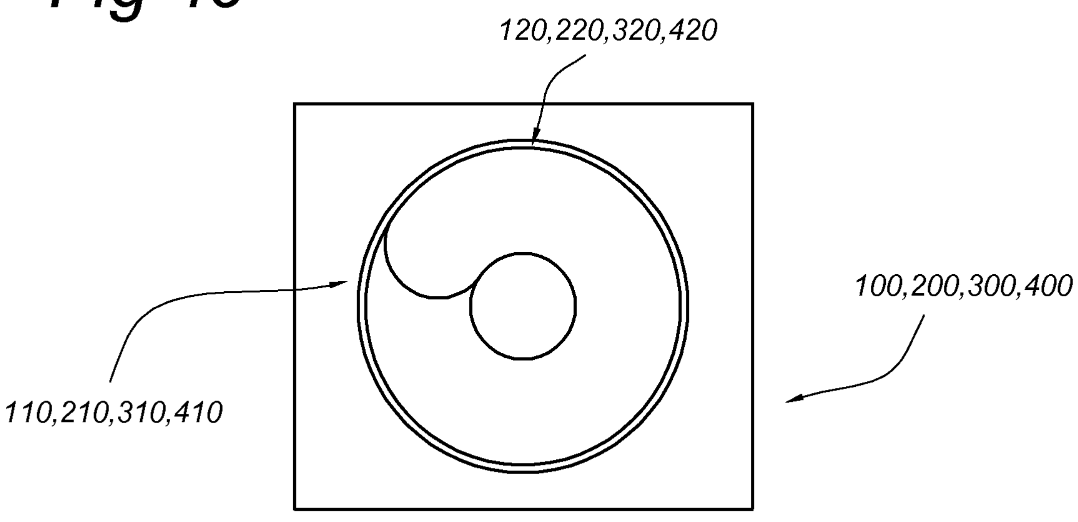

Fig 4d

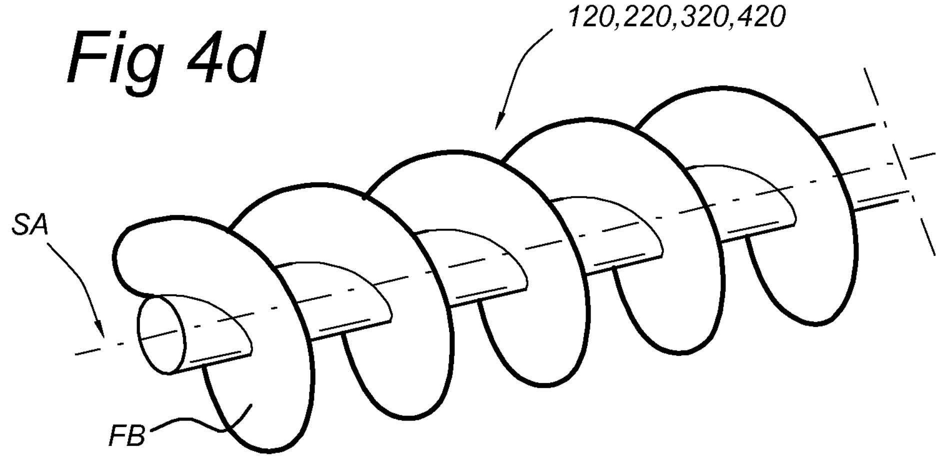

Fig 4e

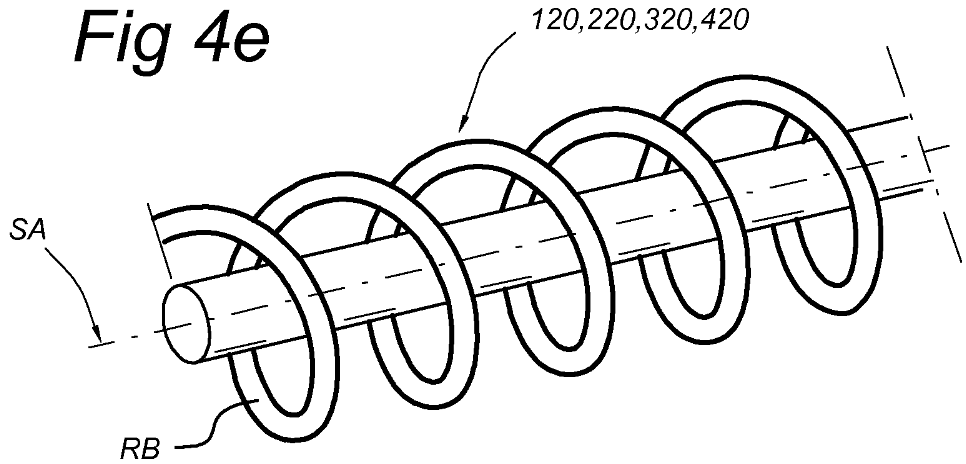

Fig 4f

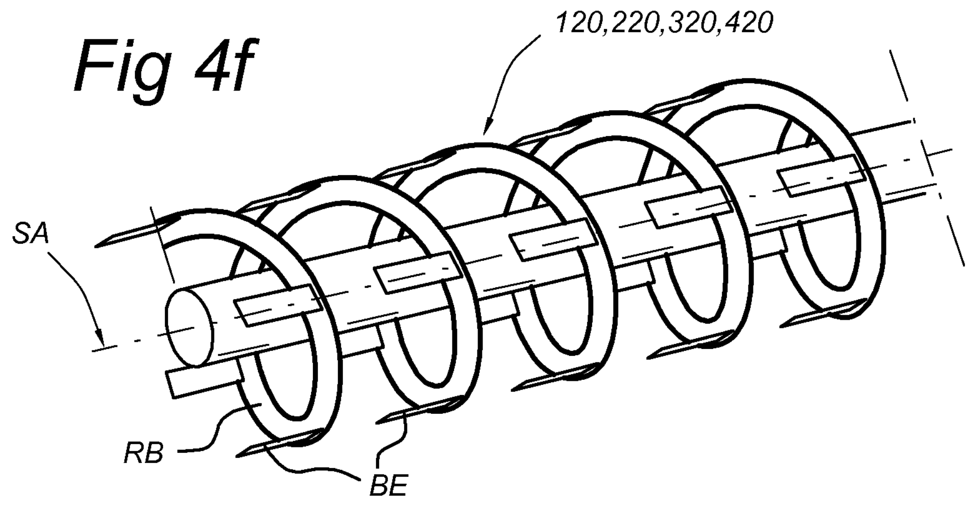

Fig 5a

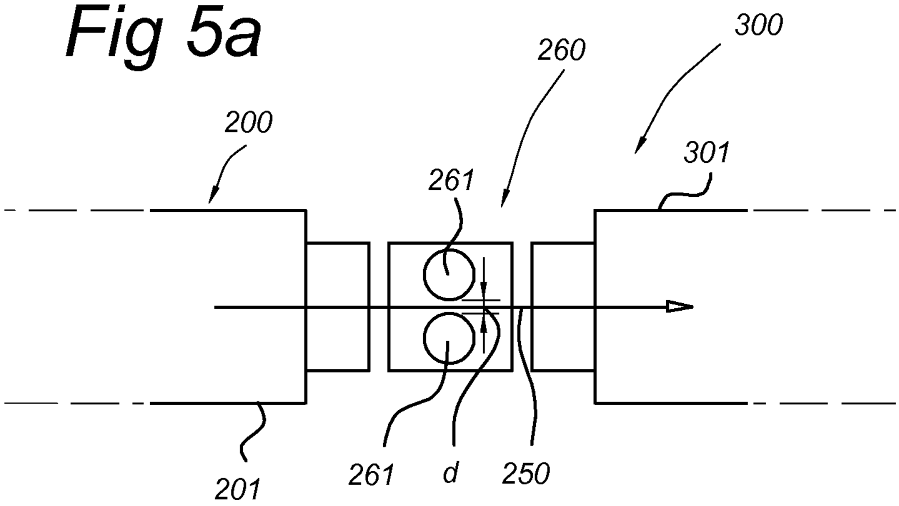
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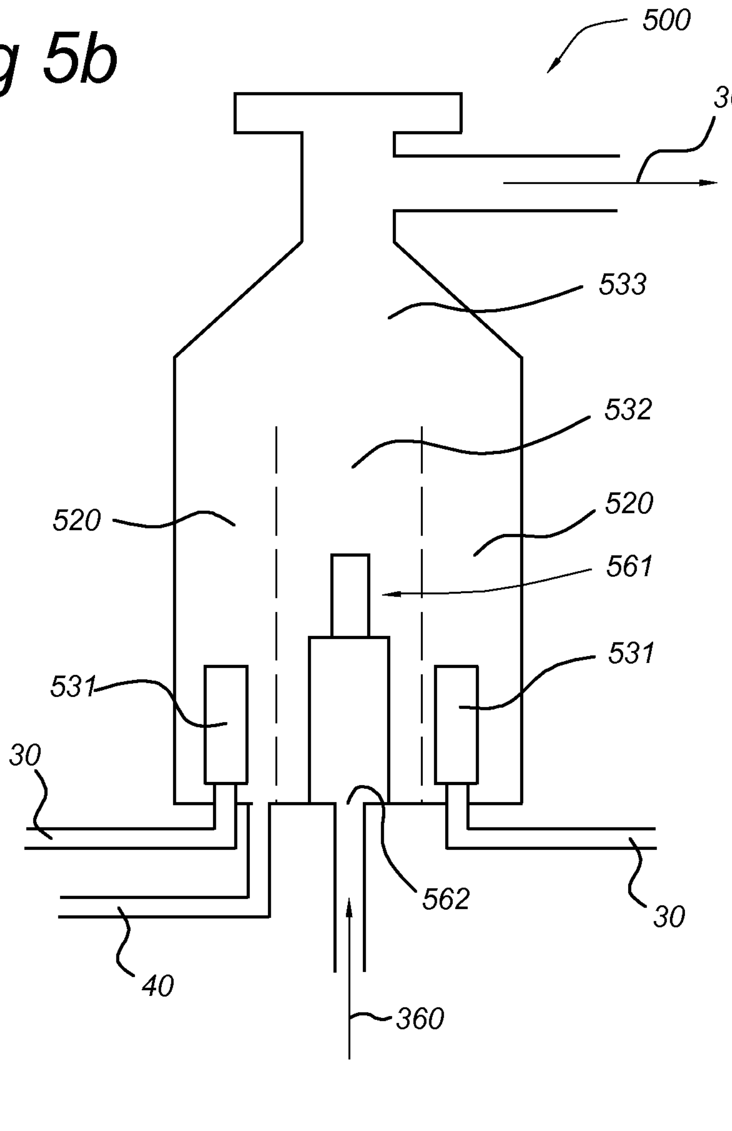
Fig 5b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INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2010/050805

A. CLASSIFICATION OF SUBJECT MATTER
INV. C10L5/44 C10B53/02
ADD.

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 C10B

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 practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2006/280669 A1 (JONES FRED L [US]) 14 December 2006 (2006-12-14) paragraphs [0032], [0033], [0040] - [0045] figures 1,2	1-9, 11-26
X	WO 2010/068099 A1 (FOXCOAL IP B V [NL]; NONNEKES WALTER [NL]) 17 June 2010 (2010-06-17)	1-17,26
A	page 25, line 24 - page 28, line 4; figures 1-8 page 22, lines 23-29 abstract; claims	18-25

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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"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

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Date of the actual completion of the international search	Date of mailing of the international search report
12 August 2011	23/08/2011

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Bertin, Séverine

INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2010/050805

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	DE 10 2007 056905 A1 (BAUKNECHT MAXIMILIAN [DE]; MORSCHETT PETER [DE]) 29 May 2008 (2008-05-29) paragraphs [0028], [0040], [0041]; claims 1,19,20,23; figures 1,2 -----	1-17,26 18-25
X	FR 2 624 876 A1 (TECHNOLOGY EXPORTS LTD [GB]) 23 June 1989 (1989-06-23) abstract; claims; figures -----	1-17
A	FR 2 786 426 A1 (ARIMPEX SARL [FR]) 2 June 2000 (2000-06-02) figure 1 abstract -----	18-26

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/NL2010/050805

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 2006280669	A1	14-12-2006	NONE		
WO 2010068099	A1	17-06-2010	NL 2003920	A	09-06-2010
DE 102007056905	A1	29-05-2008	NONE		
FR 2624876	A1	23-06-1989	EP 0345336	A1	13-12-1989
			ES 2009673	A6	01-10-1989
			WO 8905847	A1	29-06-1989
			PT 89321	A	29-12-1989
			YU 233188	A	30-06-1990
FR 2786426	A1	02-06-2000	NONE		