

SCREW CONVEYOR REACTOR AND USE FOR PYROLYSIS OR TORREFACTION OF BIOMASS

Technical Field

5 The present invention relates to screw conveyors and screw conveyor reactors which allow for the transfer of heat from a first medium to a second. Such a heat conveying medium can be formed by a fluid, including gaseous and liquid media, solid substances, such as powders, granules or grains, and various mixtures or combinations of the before-mentioned, such as sludges and dispersions.

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The present invention also concerns the use of screw conveyors in various processes.

The present invention further concerns methods of processing wood or other biomass with heat in an apparatus comprising at least one screw conveyor reactor.

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Background Art

Screw conveyors and screw conveyor reactors are common in industry. Screw conveyor reactors are mainly used for solids or for liquids, where solid content is high, so that the material to be treated does not readily flow by itself. They are also interesting alternatives to other continuous processing reactors, such as moving bed, multiple heart, and fluidized bed reactors.

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Stringent demands are placed on the constructions of screw conveyors and screw conveyor reactors in cases where sludges are to be treated and wherein large amounts of heat have to be transferred from a heating medium to a feedstock.

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The patent literature contains a large number of documents relating to various screw conveyor reactor designs.

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EP Patent No. 1 365 978 B1 discloses a helix screw fitted inside a barrel containing second

helix screw inside the first helix screw is very suitable for sludge dewatering in sewage treatment plants. Both screws can rotate at different speed and have a positively or negatively changing pitch. In the known construction bending of material of the helical screws will cause technical difficulties, at least if the material handled contains larger particles,
5 because the particle may block the clearance between these two screws.

US 20060143977 discloses the construction of apparatus for handling materials under pyrolytic conditions. The apparatus consists of a screw or screws having hollow shaft or shafts, which will carry hot gas and pyrolyze coal (in this case) to char. The apparatus
10 has sealings and support at both ends, which makes it very difficult to maintain, because of the high temperature.

US Patent No. 5,810,470 describes a helical screw mixer for mortar (cement + sand + water) where the helical screw partially contains an inner tube, which rotates with the screw and
15 supplies some part of materials like water and additives.

Very similar to the above are the constructions cited in US Patents Nos. 4,232,973 and 5,016,446. US Patent No. 7,922,384 teaches that a helical screw conveyor having a stationary inner tube will carry more easily sticky material than the helical screw itself, without the
20 stationary inner-tube.

Helical screw conveyors can also be implemented with variable diameter. These types of conveyors are suitable for slurry transport and for waste water sludge.

25 Many patents and other technical publications relate to a reactor type known as the "Discotherm" reactor, which is a family of screw reactors with rotating blades (partially cut out) and linked transport screw. This reactor can have internal rotating heating or cooling element.

30 In this kind of equipment one main problem is rotating shaft sealings, which gives rise to many issues with regard to maintenance.

Screw conveyor reactors residence time can be regulated very easily by adjusting the screw rotation speed, especially nowadays when frequency controllers for electrical motors are coming cheaper.

- 5 Within the scope of the above technology, there are some additional requirements which stem from fact that in most chemical or heat-treatment reactors the volume of the products is less than the volume of the feed.

Thus, for example, in the case of drying, roasting of minerals, low and high temperature
10 pyrolysis und gasification pyrolysis, low-high temperature torrefaction or wood pyrolysis, drying, burning of lime – in all these or similar cases – the volume is reduced when the reaction(s) advances. By contrast, only very few reactions of those common in industry are of a kind wherein the volume of the processed material will increase as the reaction advances. One example of a reaction of this kind is the formation of calcium carbonate by carbonation:
15 $\text{CaO} + \text{CO}_2 \rightarrow \text{CaCO}_3$.

In most cases the helix rotor will rotate inside a tube or barrel so that between the rotary helix and barrel there is a certain clearance. This clearance will cause back-mixing if the material is slurry or sludge, but not, if the material is a solid material, such as wood chips or
20 savings.

It is know in the art that rotary screw conveyors can be constructed with stationary heat transfer parts.

- 25 US Patents Nos. 7,947,155, 7,922,384 and 6,855,475 relate to various screw conveyor constructions which reduce problems caused by adherence of material to metal parts within the conveyor. In particular, US 7,922,384, which already was briefly discussed above, discloses a helical screw conveyor having a stationary inner tube will carry more easily sticky material than the helical screw itself with such a stationary inner tube. US 6,855,475 discloses
30 a single screw pyrolyzer for coal wherein adhered char is pushed away by packed material under the influence of a powerful screw.

Also other dryer constructions, suitable for sludges, are known in the art. KR Published Patent Application No. 20030038288 discloses a sludge drier which uses a shaftless spiral screw to reduce sludge adhesion to the screw in order to increase sludge transferring rate. A heating device is installed around the drying chamber.

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DE 2341331 discloses a drum dryer for drying and heating powdered lime which consists of a rotating tube with surrounding auger and a snail surrounding double jacket as well as a removal device, a burner and a heat source.

- 10 WO 1997037184 discloses a device for heat-treating bulk materials in feed screws and bulk material drying method.

Summary of Invention

15 Problem of the Art

Based on the above it can be noted that the known screw conveyors inadequately address the particular problems relating to processes where the volume of handled material changes from feed to exhaust.

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- Also the known screw conveyors do not properly deal with the problems relating to efficiency of heat transfer and to vibration of helical screws during operation. The helical screws and the reactors are oftentimes fabricated from stainless or acid proof steels. They tolerate temperatures up to 600 °C, especially ferritic steels, without any problems and will show low thermal expansion. Stainless steel grades that can withstand temperatures of up to 1150 °C are also available. Austenitic steels, especially AISI 316 L, are suitable. Probably the best steel grades are Martensitic Precipitation hardened steels (EN 4542, 4568, 4574).

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- Nevertheless, problems will remain with regard to heat transfer from heating medium to processing material.

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Solution to Problem

It is an aim of the present invention to provide for improved transfer of heat to and from the material which is being processed in a screw conveyor reactor.

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It is another aim of the present invention to improve operation of screw conveyor reactors during processing of material in which the volume of the material decreases as a result of the processing.

- 10 It is still a further aim of the present invention to provide for the use of screw conveyor reactors in biomass processing in particular for converting biomass into gas, liquid or oil.

The present invention is based on the provision of a screw conveyor reactor which comprises in combination a reactor shell, at least one shaftless screw (helical screw) which has a central
15 axis and wherein the helically/spirally wound threads define a central elongated space, and a heat transfer tube placed within the screw in the elongated space. Preferably the screw extends over at least the main portion of the heat transfer tube, in particular at least 90 % of the portion of the tube which is fitted into the reactor shell.

- 20 The reactor shell has generally an elongated shape with a first and a second end, which ends are opposite to each other. The shaftless screw is mounted to drive means at the first end of the reactor shell in such a way as to allow for rotation about the central axis. The heat transfer tube located concentrically inside the screw is fixed to the second (opposite) end of the reactor shell and connected to a source of a heat transfer medium.

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By locating the bearing and the drive means for the screw separately from the inlet of heat transfer medium, considerably much less thermal stress is exerted on the bearing of the screw. Also the construction is simplified.

- 30 According to a particular embodiment, there is in addition to the main screw or helical auger another screw with a different, preferably longer pitch, which pitch will gradually change

towards the exit end (for processed material) of the conveyor. This second screw has the opposite transport direction to that of the main auger.

5 A screw combination of the indicated kind will maintain the load (hold-up) constant at any location along the screw barrel. The at least one second screw will also reinforce the main helical auger against vibrations.

More specifically, the present screw conveyor reactor is characterized by what is stated in the characterizing part of claim 1.

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Advantageous Effects of Invention

Considerable advantages are obtained. Thus, the present screw conveyor-reactor has an improved and high heat and mass transfer capability. The envelope surface of the inner tube is, as a heat transfer area, approximately as large as the surface of a regular screw reactor, and for this reason, the heat transfer area per volume of material is greatly increased.

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In some embodiment, the heat carrier can be fed into the processed material via perforated tube (fluidized bed effect) which gives improved precision.

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Since the rotating screw is not heated, the sealing of the rotating shaft can be reliably and durably carried out.

The present invention provides for self cleaning of both inner and outer heat exchange surfaces; there is no adherence of processed material around screw, and no plugs are formed. Further, maintenance of the screw is facile and wear is reduced, in particular since with a construction of the instant kind metal to metal friction minimized.

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By the additional feature of at least one second screw, the present invention also solves at the same time multiple problems:

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- Back transport to keep hold-up constant

- Heat transfer from heat surface being inside helical screw (heating or cooling)
 - Grinding of at least partially torrefied wood
 - Peeling of surface of heat treated other material
 - Mixing of slurry or putty and/or kneading of it
- 5 • Stabilizing helical screws vibrations

Due to its advantageous construction, the apparatus can be used for a number of physical and chemical operations. In particular, the present screw conveyor reactor can be employed

- as a conveyer and dryer;
- 10 – for conductive heating, optionally using sub-atmospheric pressure;
- as a cooler of the material which is being processed in the screw conveyor; and
 - for thermochemical conversion processes, in particular of biomass and/or waste to oil, char and/or gas, preferably by pyrolysis or torrefaction.

15 Further features and benefits of embodiments will appear from the following description.

Brief Description of Drawings

20 Next, various embodiments will be examined in more detail with reference to the attached drawings.

Figure 1 shows in side-view in a schematic fashion the construction of a single end radiant tube heater type screw conveyor according to one embodiment;

Figure 2 shows in side-view a similar depiction of a heater tube apparatus;

Figure 3 shows in side-view a cooler tube apparatus;

25 Figure 4 shows in side-view in a schematic fashion a catalytic gas burner and heat tube reactor; wherein the central tube is perforated for allowing direct heating of processed material with flue gases;

Figure 5 shows in side-view a catalytic gas burner/heater type screw conveyor according to a further embodiment;

30 Figure 6 shows in side-view the principal construction of a screw conveyor according to a further embodiment suitable as a reactor or heat exchanger, provided with a burner and steam

coil for transfer of steam to the processed material through perforations in the heat transfer tube;

Figure 7 shows in side-view the principal construction of a conveyor suitable for mixing, dosing, cooling and heating, wherein the appropriate medium (gas/liquid/paste/vapour) is being fed through the central tube into the processed material;

Figures 8A to 8C show in side-view various configurations of the central tube for creating suitable flow of the processing material inside the reactor;

Figure 9 shows the principal construction of a torrefaction plant with feed assembly, outlet and two screw conveyor reactors;

Figure 10 shows two alternative embodiments of auger (screw) couplings to drive-end; the upper embodiment of Figure 10 works with drive direction change;

Figures 11a to 11c show in cross-section the wear parts on the inside of the reactor shells;

Figure 12 shows in side-view the principal construction of an alternative embodiment of a conveyor with a second screw;

Figure 13 shows in side-view the principal construction of another alternative embodiment of a conveyor with a second screw;

Figures 14a and 14b show cross-sections of the two alternative embodiments of the previous screw conveyors;

Figure 15 shows a detail of a screw conveyor depicted in Figure 12 with the edge of the helical screw rotating near the inner surface of the barrel; and

Figure 16 shows the relative positions of the helical screw and a rifle or groove in an embodiment of the screw conveyor.

Embodiments

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For the purpose of the present invention, the term “tube” is used for designating a cylindrical object which has two open opposite ends, or which has one open and one closed end.

The heat transfer tube is typically manufactured from a material capable of conducting heat through the wall thereof. The outer cylindrical surface of the tube is also referred to as the envelope surface thereof. In addition to working as a heat transfer surface it also takes up the

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material which is to be processed in the apparatus. The material is transported (slid) along the surface by the action of the at least one rotating screw which shifts and forces the material along the surface from one end of the rotary screw conveyor to the other.

- 5 “Shaftless screw” is used synonymously with “auger” and “helical screw” to designate a continuous turn of threads which forms a spiral which defines a central, typically cylindrical space.

10 In the present technology, the heat transfer tube is typically fit inside the screw such that there will be a clearing between the inner side of the screw threads and the cylindrical surface of the tube to avoid metal to metal friction.

Although it is preferred to have heat transferred to or from the processed material through the heat transfer tube, it is clear that also the barrel or reactor shell can be provided with a heating
15 means such that the processed material is subjected to heat transfer from both sides of the annular channel formed between the inner surface of the barrel and the outer surface of the heat transfer tube.

Typically, it is preferred introduce a heat source from the exit head of reactor, so as to achieve
20 a counter-current temperature difference between heat source and the material which to being processed.

Further, in preferred embodiments, inside the reactor shell there are arranged wear-out elements, which can be changed by pulling them out, when the shells are open. Typically, the
25 wear-out elements are steel tube, steel rods or other steel elements which can be changed.

Turning now to the drawings, it can be noted that the screw conveyor reactors shown in Figures 1 to 8 comprise a reactor shell 1, 11, 21, 31, 41, 51, 61, 71, 81, 91 having generally an elongated shape with a first and a second end, which ends are opposite to each other; a
30 shaftless screw 5, 15, 25, 35, 45, 55, 65, 75, 85, 95 having a central axis, mounted to drive means 8, 18, 28, 38, 48, 58, 68, 78, 88, 98 at the first end of the reactor shell to allow for

rotation about the central axis; and a heat transfer tube 4, 14, 24, 34, 44, 54, 64, 74, 84, 94 located concentrically inside the shaftless screw, fixed to the second end of the reactor shell and connected to a source of a heat transfer medium 6, 16, 26, 36, 46, 56, 66.

- 5 As shown in the drawings, the heat transfer tubes 4, 14, 24, 34, 44, 54, 64, 74, 84, 94 have an open end and an opposite closed end. The closed end faces the drive-end of the screw 8, 18, 28, 38, 48, 58, 68, 78, 88, 98.

- 10 In the embodiments, the reactor shell typically has an inlet 2, 12, 22, 32, 42, 52, 62, 72, 82, 92 for fresh feed of a material to be processed in the reactor, and an outlet 3, 13, 23, 33, 43, 53, 63, 73, 83, 93 for material processed in the reactor.

The inlet of the fresh feed is located adjacent to the second end of the reactor shell, and the outlet of the processed material is located adjacent to the first end of the reactor shell.

- 15 In all of the embodiments shown, the shaftless screw 5, 15, 25, 35, 45, 55, 65, 75, 85, 95 is capable of conveying material along the envelope surface of the heat transfer tube from a first zone adjacent to the inlet to a second zone adjacent to the outlet. The envelope surface of the heat transfer tube forms a heat transfer surface capable of transferring heat to or from the material to be processed in the reactor.
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- Figure 1 shows the basic configuration of an embodiment of the present technology, viz. a single end radiant tube heater type screw conveyor, wherein the heat is provided by gas and air fed into the inner tube 6 of the heat transfer tube 4. The heated gas flows through the heat transfer tube and exits through the flue gas outlet, reference numeral 7.
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- The screw conveyors of Figures 2 to 8 are configured in a similar fashion: each heat transfer tube has an inlet for fresh heat transfer medium and an outlet 7, 17, 27, 37, 47, 57, 67 for spent heat transfer medium. And the heat transfer tubes have closed ends next to the first end of the reactor shell.
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Figures 1, 2 and 3 show screw conveyor reactors the heat transfer tube comprises at least one first open-ended tube 9, 19, 29 fitted inside a second, surrounding tube 4, 14, 24, having a closed end, wherein the second tube has an envelope surface which forms the heat transfer surface of the heat transfer tube. As apparent from the same drawings, in the screw conveyor
5 reactors there is a clearance between the end of the first tube 9, 19, 29 and the closed end of the second tube 4, 14, 24 to allow for flow of heat transfer media between the first to the second tube or vice versa.

Figures 1 and 2 show heater type reactors, in which the first tube 9, 19 is connected to a source
10 of a fresh heat transfer media 6, 16, and Figure 3 is a cooler type apparatus in which the second tube 24 is connected to a source 26 of fresh heat transfer media (coolant).

Figure 4 shows a catalytic gas burner combined with the heat transfer tube which in addition is provided with perforations to provide for direct heating of the material with flue gases. Thus,
15 the heat transfer tube 34 is provided with catalytic combustion beds 39 which heat up the gas and air from the gas/air inlet 36. The envelope surface of the heat transfer tube 34 is perforated so as to form apertures 37 which allow for the passage of flue gases from the inside of the heat transfer tube into the processed material. 15. In embodiment shown the heat transfer tube comprises several catalytic reaction zones 39 capable of generating heat by combustion of gas,
20 although it is possible to achieve heat production already with one catalytic zone.

Figure 5 shows a screw conveyor reactor, similar to the heaters of Figures 1 and 2 with the difference to, for example, the heater of Figure 1 that the gas is heated in catalyst zones located inside the first tube 39.
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Figure 6 shows a burner reactor which comprises internal tubes for generating the steam and directing it straight to materiel dried/conveyed. Thus the burner of Figure 6 comprises a steam coil surrounding the first tube 59. The second tube 54 has perforations in its envelope surface to allow for flow of heat transfer media, by steam in the case shown in Figure 6, to the
30 material processed in the reactor. Naturally, it is possible to reverse the direction of heat or steam flow when operating an apparatus of the kind shown as a cooler.

Figure 7 shows a tube shaft 64 capable of providing mixing, dosing, cooling or heating. The tube is connected to a source of heat transfer medium selected from air, gas, steam, liquid, paste, solid material and combinations thereof.

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Figures 8A to 8C show heat transfer tubes 74, 84, 94, exhibiting a first cylindrical zone having a first diameter, and a second cylindrical zone having a second diameter greater than the first diameter. As can be seen in the drawings, the first and the second cylindrical zones are connect by conical collar zones which are capable of forming a wedging zone between the
10 inner surface of the reactor shell and the envelope surface of the heat transfer tube.

Typically, the conical collar zones form inclined surfaces standing at an angle of 85 – 45 degrees against the central axis of the shaftless screw 75, 85 and 95.

15 The inner tube designs shown in Figures 8A to 8C are intended for creating plugs inside the reactor. The variable diameter tube achieves plugs inside the reactor: in the end, in the beginning, in the center and/or fragmented, connected with tube (creates plug which prevents gases from escaping in the wrong direction.

20 In one further main embodiment, the screw reactor is configured for use in cases where the processed material will change volume during processing. As mentioned above, the weight and volume of the processed material of heat treatment will change and be reduced as the material travels through a rotary screw conveyor. In the case of calsium carbonate burning the volume reduction is 20 to 40% , depending of crystal morphology. In the case of wood
25 torrefaction the reduction in volume is up to 50 % depending on helical augers construction. The torrefied wood has a crushing strength about 1/3 of the corresponding strength of original wood chips. If the helical screw rotates quite tightly against the barrel and screws front is inclined it will crush the partially torrefied wood chips and densify the material, which results in a reduction of bulk volume.

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In the case of mineral heat treatment the attraction influence will increase gas escape and heat transfer. Attraction influence means that particles are partially peeled from the aimed comer and the untreated inner core is liberated for new reactions. This grinding action can be achieved also so that the barrel is rifled or grooved at least at the exit end, where material is
5 already torrefied at least partially.

The rotation of the rifles or grooves must be strait or curved to opposite direction of the helical screws transport direction.

10 In all cases, volume reduction along with the heat treatment will happen and is advantageous for further transport and processing. Grinding of torrefied wood will consume electrical energy or shaft power only 1/3 to 1/5 of grinding raw wood chips. A product with smaller particle size will be heated more easily, transported more easily and compacted or pelletized more easily. Lubricants and other additives are easier to mix to the grinded powder as to the
15 original long chips particles.

In the particular embodiment the reactor consists of a barrel, helical screw and heat transfer surface inside the helical screw. The barrel is also heated. In most of the cases it is preferable to introduce a heat source in from the exit head of reactor, to achieve counter-
20 current temperature difference, between heat source and the treated material.

The helical screw is stabilized with other screw, having longer pitch and to the other direction as the main transport screw. In addition to this embodiment we can have also rifled or grooved barrel. The stabilized screw can preferable have progressive pitch, for keeping
25 hold-up constant, when treated materials volume is decreasing. Main screw at least at the exit-end preferably has inclined edges. The angle of inclined edge will be from 89 to 45 degrees.

Based on the above the present reactor comprises, in such an embodiment, not only one helical
30 transport screw of the kind described above, but also connected to this screw another screw. This second screw has a higher pitch and provides reverse transporting relative to the main

transport screw, so that the other screw will compensate for the volume change of the processed material, thus keeping the material volume constant inside of the reactor (and along the reaction path therein).

- 5 A preferred embodiment generally comprises a first screw having a first pitch and first direction of thread turns and at least one second screw having a second pitch and a second direction of thread turns, said first and said second directions being different. Preferably the first and the second pitches are different.
- 10 In one embodiment, the two screws are connected to each other so that the second screw will support the main transport screw and will reduce its vibrations.

Figures 12 and 13 illustrate this particular mode of operation with reference to two slightly different embodiments.

- 15 In Figure 12, reference numeral 174 relates to the main screw, numeral 172 is the barrel or shell of the screw conveyor and numeral 173 is the counter-screw. Numeral 174 relates to the joining point of these two screws. Numeral 175 is the plate rotating the screw and numeral 176 is the shaft which is connected to a power source used for rotating the screw. Numeral 177 is
- 20 the inner tubular heat transfer surface.

In one embodiment, there are two or more second screws. In another embodiment, which can be combined with any of the fore-going, there are rifles or grooves in the inner surface of the reactor shell.

- 25 In another embodiment, the angle of the thread turns of the first screw and of the rifles or grooves is less than 90 degrees with respect to the central axis of the screw.

- In all of the above embodiments, there can be arranged drive-locks for at least one screw,
- 30 capable of being opened with a hatch for screw change or reparation.

Figure 9 shows the use of screw conveyor reactors of the above kind in a torrefaction apparatus.

The apparatus comprises two barrels 101 and 102. Both of the barrels have a central axis and they are preferably displaced in parallel and essentially in horizontal position. The first barrel 101 is mounted vertically above the second barrel 102.

At the end of first barrel 101 there is an aperture and a conduit 103 from where the dried biomaterial falls to the second barrel 102 under the influence of gravity. At the end of both barrels 101, 102 there are the drives of augers at the same side, 104 and 105. The drive-locks are easily opened by a hatch 111. Inside of both barrels 101, 102 there are the rotating auger conveyers 106 and 107. The heating tubes 108 and 109 are symmetrically placed inside the auger conveyers 106 and 107, as discussed above.

Figures 11a to 11c shows the wear parts inside the barrels. In Figures 11a to 11c the bottom of the barrels 141, 151, 161 is covered with steel rods (parts 162, see Figure 11c), which can be pulled out and changed as the wear is too great. Instead of the bottom rods there can be used also a spout 152 made from 1–3 mm steel, covering the lower half of the barrel. This spout can also be changed quickly when it wears out.

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Turning once again to Figure 9, it can be noted that the drive couplings at the drive-end are numbered 112 and 113. The feed stock bin is shown as number 114 and the preheating mantel (optional) as number 115. The condenser for gas coming from torrefied material has been assigned numeral 116.

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The first, upper barrel 101 is only for drying the material and its off-gases are not mixed to the main torrefying gases, because they only dilute burnable gases with water vapours. The burning gases come only from the second barrel 102. In both cases the escape of the gases will take place through the upper parts of the perforated barrels 101, 102. The blower of combustible gas has been assigned numeral 117.

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Figure 10 shows two alternative embodiments 121/122/123 and 131/132, respectively, for the auger couplings to the drive-end. Embodiment 121/122/123 works with drive direction change.

- 5 The torrefaction plant shown in Figure 9 can be operated as follows:

The drive ends of helical augers are snap-locks for rapid removal and cleaning of screws. The drive-lock is easily opened via hatch 111. When the auger is rotating in two directions and when auger is rotating in one direction only. When the direction of revolution is changed, the
10 drive lock is opening.

The heat distribution tubes located inside the helical augers, are preferably of a type of recuperative burners with pre-heat for the in-coming air and recirculation of flue gas.

- 15 The entire piece of equipment is assembled from two separate helical augers where the uppermost is the feed and drying zone with perforated barrel tube for drying gas removal, from where the dried material is falling to the lower and hotter space, from where the torrefaction gas is collected for burning. Helical auger drive is on the opposing end to the feed end.

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Both heating tubes are assembled directly to the heat source from the other end and the helical gear drive is on the other end. Both helical auger drives are at the same end. It is only necessary to open drive end cap of for maintenance.

- 25 Helical augers are reversible if snap lock like the one shown in Figure 10 is used.

The regulation of the torrefication temperature is arranged so that the second (lower) helical augers revolution are regulated with adaptive feed-back from the outlet ends temperature sensor.

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Option for corrosion prevention (acetic acid + formic acid) can be made with feeding wood ash, Ca-compounds, Mg -compounds 0.5-5 % mixed with the biomass feed. They neutralize these acids in gas-atmosphere, but they do not affect the ability of acetic acid to depolymerize hemicellulose inside the biomass material. The actually formed Ca-acetate will break up into

5 CaCO_3 + acetone (CH_3COCH_3) and CaCO_3 will again form Ca-acetate. The break-up happens at 160 °C.

Similar reactions happen with K- and Na-salts, but they are stable at higher temperatures. So in case of Ca-acetate it is not actually chemically consumed.

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The 'torrgas' from auger-space is collected, cooled and optionally condensed for improving gases heat value. The condensate flows through a bed packed with lime stone or dolomite stone for neutralization and purification. The dried gas is stored slightly pressurized in a gas vessel and led to burn. The total process is exothermic, but start-up must happen with external

15 fuel.

As an option the preliminary pre-heating of feed material is arranged to happen with the first cooling stage of the 'torrgas', in the feed bin's mantel. Later cooling is made by preheating burning air at the same time and/or finally with water. This option can be used when the

20 humidity of the feed material is very high (greater than 50%) or the extra heat does have another suitable use.

The auger's location in the barrel is in one embodiment asymmetric, so that there is free space above the screw for the free and slow flowing of the gases to the cooling, condensing and

25 burning.

At the bottom of barrels there is a number of wear parts, which can easily be changed when worn-out enough.

30 The device allows the feed material heat treatment at temperature up to 1000 °C.

Industrial Applicability

The present technology can be used for drying a variety of materials. The presented apparatus can also be used as conveyer and dryer.

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In the apparatus conductive heating can be employed. The pressure can be varied, operation can be carried out at ambient pressure or at sub-atmospheric pressure or overpressure.

The presented apparatus can also be used as cooler.

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Generally, when processing material in the screw conveyor, the material transported through it can be heated, cooled or dried.

Typically, the heating and cooling media can comprise water, glycol, steam, hot oil and

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combinations thereof. However, it is also possible to employ electrically heating for the screw reactor. These kinds of applications are suitable for thermochemical conversion processes, for example for producing oil, char and gas or mixtures thereof from biomass or waste materials.

Typical examples of applications include processes for treatment of biomass, biofuels, the

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food and dairy industry, in paper and pulp processing, minerals, chemical and petrochemical industries

In the processing of biomass, such as wood chips or similar lignocellulosic material, the raw-material, e.g. wood chips, first needs to be dried. Drying can be performed using pre-heated

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air, obtained from any source of heated gas, such as gas engine exhaust gas.

The gasification can be carried out in two steps. The present screw conveyor can be used in a first step for drying of feed. The moisture content of chips is reduced from a typical content of approximately 45 % for fresh wood to a maximum of 5 %.

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In the next step, the pyrolysis screw, any suitable equipment can be used, but also a screw conveyor reactor as described herein. In that case, the pre-heated wood chips are fed through the center tube of the pyrolysis screw. In the pyrolysis process, the heat is provided by the hot raw gas which circulates in the outer jacket of the pyrolysis screw.

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The pyrolysis process generates a raw gas, coke and tar particles at approx. 700 °C.

Various configurations are possible: one to several vertical screws, one or several horizontal screws – for example one to four augers.

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As discussed above, another application of the present invention is in the field of torrefaction. Thus, a torrefaction apparatus for biomass comprises at least one first screw conveyor reactor of the above-described kind, wherein the material is merely dried; and at least one second screw conveyor reactor of the above-described kind, wherein the material is merely torrefied.

15 Preferably, the first and the second screw conveyor reactors are separated such that the off-gases of the reactors are not mixed together.

Generally, a torrefaction plant can be constructed by providing two joined barrels, which are arranged vertically one below the other. At the end of both barrels there are drives of augers,
20 which locks are easily opened by a hatch. Inside of both barrels there are rotating auger conveyers having heating tubes inside them. Escape of gases from barrels will happen through the upper parts of the barrels which is perforated and the gas can be reused for heating the plant. Inside the barrels there are wear parts, which can be replaced.

25 The following clauses characterize embodiments relating to torrefaction plant and method of using such plant:

1. Torrefaction plant for biomass with easy maintenance, characterized in that it comprises:

- a first auger conveyor reactor, where material is merely dried;
- 30 – a second auger conveyor reactor, where material is merely torrefied;

- inside the rotating auger conveyors heat distribution tubes are located, so that the lower and upper heat distribution tubes are separated and the off-gases are also separated, not mixed together;
- drive-locks for screws opening with a hatch for screws change or repairing;
- 5 – inside the main barrels wear-out elements are located, which can be changed by pulling them out, when the barrels are open.

2. Torrefaction plant according to clause 1, characterized in that the barrels are perforated from the upper part, allowing from upper barrel off-gases escape merely as steam from the dried biomass and in the lower barrel off-gases are going to be burned and used in both barrels as heat source.

3. Torrefaction plant according to clause 1 or 2, characterized in that the barrels containing auger conveyors contain an inside tube in the barrel, which can be changed or rotated inside of the barrel and outside of the rotating helical auger torrefaction plant.

4. Torrefaction plant according to any of clauses 1 to 3, characterized in that the wear-out elements are steel tube, steel rods or other steel elements which can be changed.

5. Torrefaction plant according to any of clauses 1 to 4, characterized in that auger conveyors are reversible.

6. Method to operate torrefaction plant according to any of clauses 1 to 5, characterized in that basic or basic reacting material is co-feed with biomass in order to neutralize the volatile acids which are released by heating from the biomass .

7. Method to operate torrefaction plant according to clause 6, characterized in that that basic reacting material is CaO , Ca(OH)_2 or CaCO_3 .

8. Method to operate a torrefaction plant according to clause 6, characterized in that basic reacting material is wood ash.

9. Method to operate a torrefaction plant of any of clauses 1 to 5 according to any of clauses 6 to 8, characterized in that the outlet's material temperature is regulated with the second barrel's residence time, it means with the revolutions of the screw conveyor and the drier
 5 barrel temperature is regulated with adjusting the heat source tube burner gas-feed.

10. Method to operate a torrefaction plant of any of clauses 1 to 5 according to any of clauses 6 to 9, characterized in that the pyrolysis gas emitted is cooled, the water condensed out and cleaned with Ca-compounds before it is used for burning.
 10

Reference Signs List

15	1, 11, 21, 31, 41, 51, 61, 71, 81, 91	barrel (reactor shell)
	2, 12, 22, 32, 42, 52, 62, 72, 82, 92	inlet of feedstock
20	3, 13, 23, 33, 43, 53, 63, 73, 83, 93	outlet of processed material
25	4, 14, 24, 34, 44, 54, 64, 74, 84, 94	heat transfer tube
	5, 15, 25, 35, 45, 55, 65, 75, 85, 95	shaftless (helical) screw
30	6, 16, 26, 36, 46, 56, 66	inlet of heat transfer medium
	7, 17, 27, 37, 47, 57, 67	outlet of heat transfer medium
35	8, 18, 28, 38, 48, 58, 68, 78, 88, 98	drive-end of screw (plate and shaft assembly)
40	9, 19, 29, 39, 49, 57, 67	outlet of heat transfer medium

	101, 102	barrel
	103	conduit
	104, 105	drives for augers
5	106, 107	rotary augers
	108, 109	heating tubes
	111	hatch
	112, 113	drive couplings
	114	feed stock bin
10	115	preheating mantel
	116	gas condenser
	117	gas blower
	118	conduit
	119	product bin
15	121, 122, 131	auger couplings
	123	auger
	132	auger with couplings
	141, 151, 161	barrel
	142	wear tube
20	143, 153, 163	screw
	144, 154, 164	fire tube (heat transfer tube)
	152	spouts
	162	rods
	171, 181	main screw
25	172, 182	barrel or shell of the screw conveyor
	173, 183	counter-screw
	174, 184	joining point between the main screw and the counter screw
	175, 185	rotating plate of screw
	176, 186	shaft coupled with power source for rotating screw
30	177, 187	inner tubular heat transfer surface
	191	barrel
	192	rifle
	201	main screw
	202	counter screw connections
35	211	edge of the helical screw)
	212	helical screw
	213	barrel
	221	barrel
	222	helical screw
40	224	angle
	227	rifle or groove

Citation List

Patent Literature

- 5 EP Patent No. 1 365 978
US 20060143977
US Patent No. 5,810,470
US Patent No. 4,232,973
US Patent No. 5,016,446
- 10 US Patent No. 7,922,384
US Patent No. 7,947,155
US Patent No. 6,855,475
KR Patent Application No. 20030038288
DE 2341331
- 15 WO 1997037184

Claims:

1. Screw conveyor reactor comprising
 - a reactor shell having generally an elongated shape with a first and a second end,
5 which ends are opposite to each other;
 - a shaftless screw having a central axis, mounted to drive means at the first end of the reactor shell to allow for rotation about the central axis; and
 - a heat transfer tube located concentrically inside the shaftless screw, fixed to the
10 second end of the reactor shell and connected to a source of a heat transfer medium.
2. The screw conveyor reactor according to claim 1, wherein the reactor shell has an inlet for fresh feed of a material to be processed in the reactor, and an outlet for material processed in the reactor.
- 15 3. The screw conveyor reactor according to claim 2, wherein the inlet of the fresh feed is located adjacent to the second end of the reactor shell.
4. The screw conveyor reactor according to claim 2 or 3, wherein the outlet of the processed material is located adjacent to the first end of the reactor shell.
- 20 5. The screw conveyor reactor according to any of claims 1 to 4, wherein the shaftless screw is capable of conveying material along the envelope surface of the heat transfer tube from a first zone adjacent to the inlet to a second zone adjacent to the outlet.
- 25 6. The screw conveyor reactor according to claim 5, wherein the envelope surface of the heat transfer tube forms a heat transfer surface capable of transferring heat to or from the material to be processed in the reactor.
- 30 7. The screw conveyor reactor according to any of the preceding claims, wherein the heat transfer tube has an inlet for fresh heat transfer medium and an outlet for spent heat transfer medium.

8. The screw conveyor reactor according to any of the preceding claims, wherein the heat transfer tube has a closed end next to the first end of the reactor shell.
9. The screw conveyor reactor according to any of the preceding claims, wherein the heat transfer tube comprises at least one first open-ended tube fitted inside a second, surrounding tube having a closed end, wherein the second tube has an envelope surface which forms the heat transfer surface of the heat transfer tube.
10. The screw conveyor reactor of claim 9, wherein there is a clearance between the end of the first tube and the closed end of the second tube to allow for flow of heat transfer media between the first to the second tube or vice versa.
11. The screw conveyor reactor according to any of the preceding claims, wherein
- the first tube is connected to a source of a fresh heat transfer media; or
 - the second tube is connected to a source of fresh heat transfer media.
12. The screw conveyor reactor according to any of the preceding claims, wherein the envelope surface of the heat transfer tube has perforations to allow for flow of heat transfer media to or from the material processed in the reactor.
13. The screw conveyor reactor according to any of the preceding claims, wherein the heat transfer tube comprises a steam coil concentrically fitted inside the heat transfer tube.
14. The screw conveyor reactor according to claim 12 or 13, wherein the heat transfer tube comprises perforations for allowing flow of steam or heated gas from the heat transfer tube to material being processed in the reactor.
15. The screw conveyor reactor according to any of the preceding claims, wherein the heat transfer tube comprises one or several catalytic reaction zones capable of generating heat by combustion of gas.

16. The screw conveyor reactor according to any of the preceding claims, wherein the source of heat transfer medium is capable of providing air, gas, steam, liquid, paste, solid material or a combination thereof.
- 5 17. The screw conveyor reactor according to any of the preceding claims, wherein the heat transfer tube exhibits a first cylindrical zone having a first diameter and a second cylindrical zone having a second diameter greater than the first diameter.
- 10 18. The screw conveyor reactor according to claim 17, wherein the first and the second cylindrical zones are connect by conical collar zones which are capable of forming a wedging zone between the inner surface of the reactor shell and the envelope surface of the heat transfer tube.
- 15 19. The screw conveyor reactor according to claim 18, wherein the conical collar zones form inclined surfaces standing at an angle of 85 – 45 degrees against the central axis of the shaftless screw.
- 20 20. The screw conveyor reactor according to any of the preceding claims, comprising a first screw having a first pitch and first direction of thread turns and at least one second screw having a second pitch and a second direction of thread turns, said first and said second directions being different.
- 25 21. The screw conveyor reactor according to claim 20, wherein said first and said second pitches are different.
22. The screw conveyor reactor according to claim 20 or 21, wherein the two screws are connected to each other so that the second screw will support the main transport screw and will reduce its vibrations.
- 30 23. The screw conveyor reactor according to any of claims 20 to 22, wherein there are two or more second screws.

24. The screw conveyor reactor according to any of claims 20 to 23, wherein there are rifles or grooves in the inner surface of the reactor shell.

25. The screw conveyor reactor according to any of claims 20 to 24, wherein the angle of the thread turns of the first screw and of the rifles or grooves is less than 90 degrees with respect to the central axis of the screw.

26. The screw conveyor reactor according to any of the preceding claims, comprising drive-locks for at least one screw, capable of being opened with a hatch for screw change or repair.

27. The screw conveyor reactor according to any of the preceding claims, wherein inside the reactor shell there are wear-out elements, which can be changed by pulling them out, when the shells are open.

28. The screw conveyor reactor according to any of the preceding claims, wherein the wear-out elements are steel tube, steel rods or other steel elements which can be changed.

29. Use of a screw conveyor reactor according to any of claims 1 to 28

- as a conveyer and dryer;
- for conductive heating;
- as a cooler of the material which is being processed in the screw conveyor; and
- for thermochemical conversion processes, in particular of biomass and/or waste to oil, char and/or gas, preferably by pyrolysis or torrefaction.

25

30. Torrefaction plant for biomass comprising

- at least one first screw conveyor reactor as claimed in any of claims 1 to 28, where material is merely dried; and
- at least second screw conveyor reactor as claimed in any of claims 1 to 28, wherein the material is merely torrefied;

30

wherein the first and the second screw conveyor reactors being separated such that the off-gases of the reactors are not mixed together.

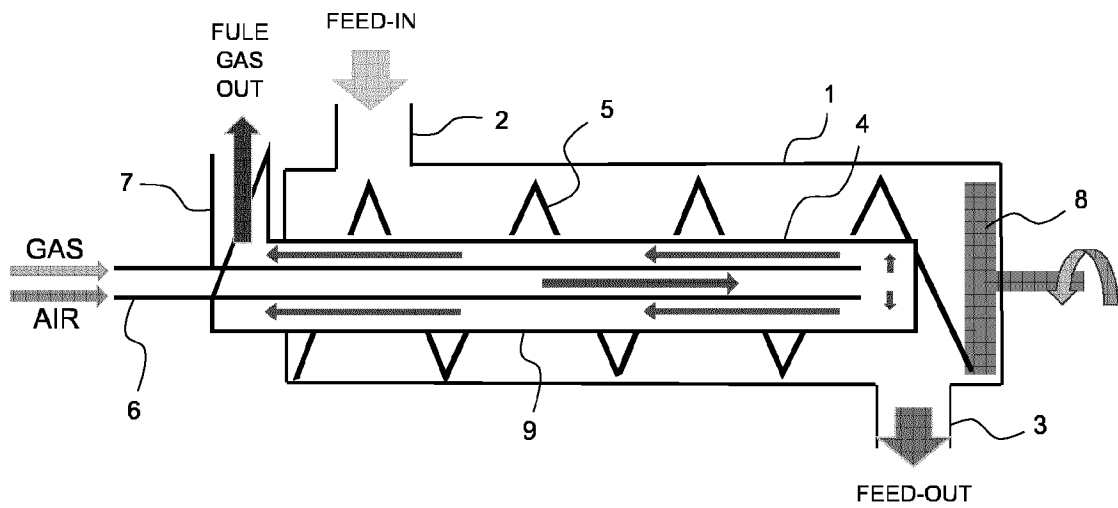


Fig. 1

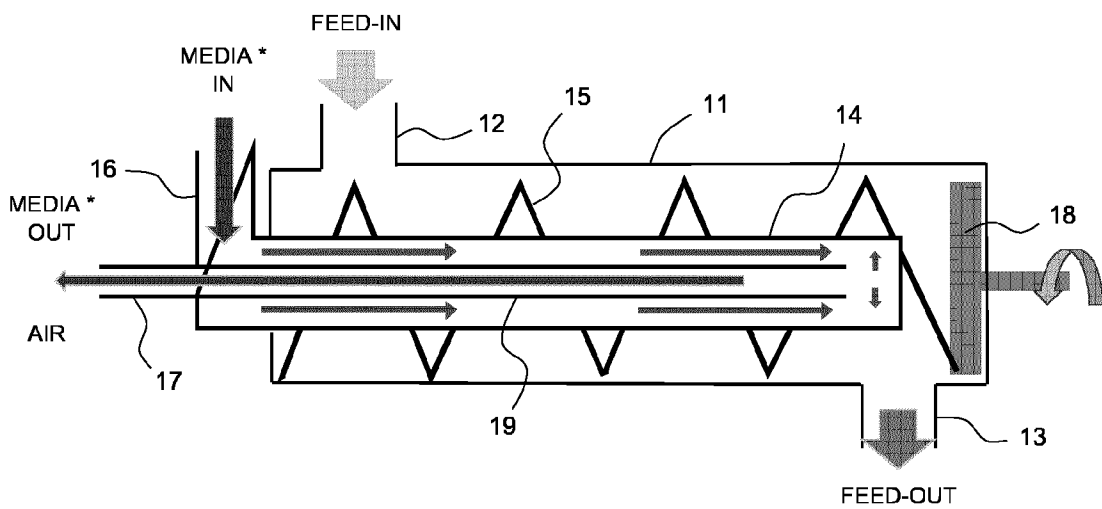


Fig. 2

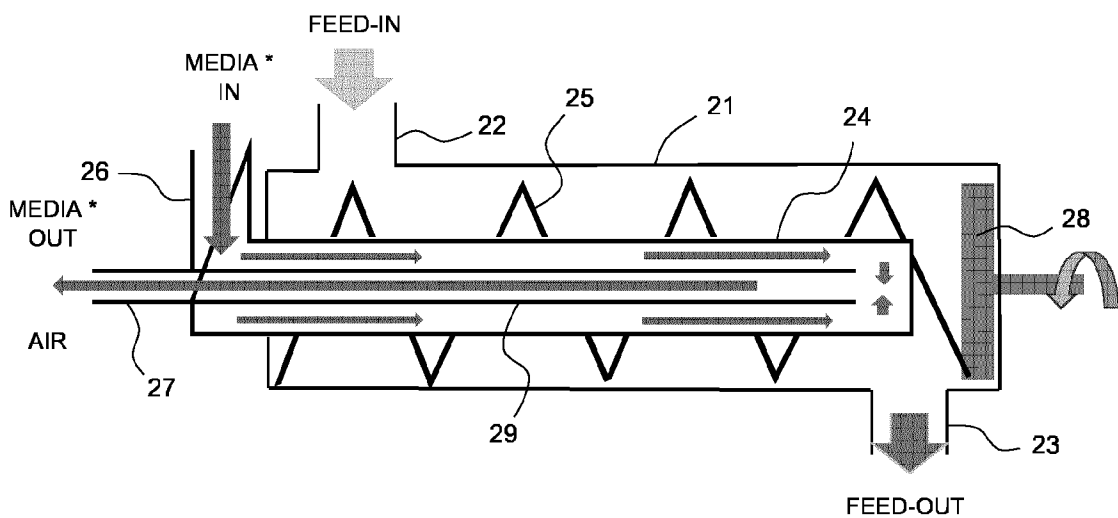


Fig. 3

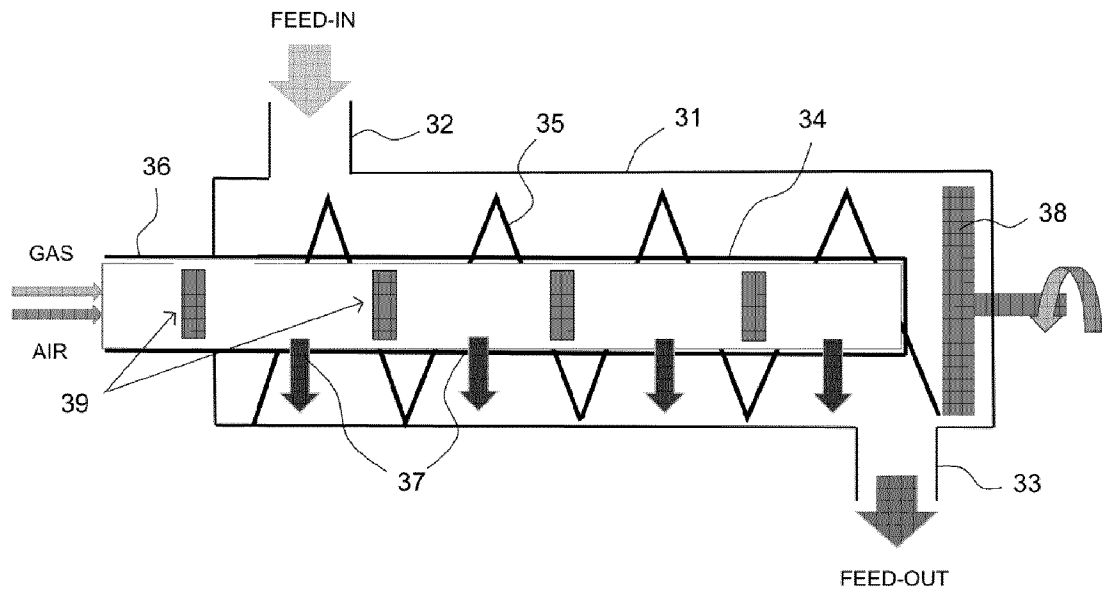


Fig. 4

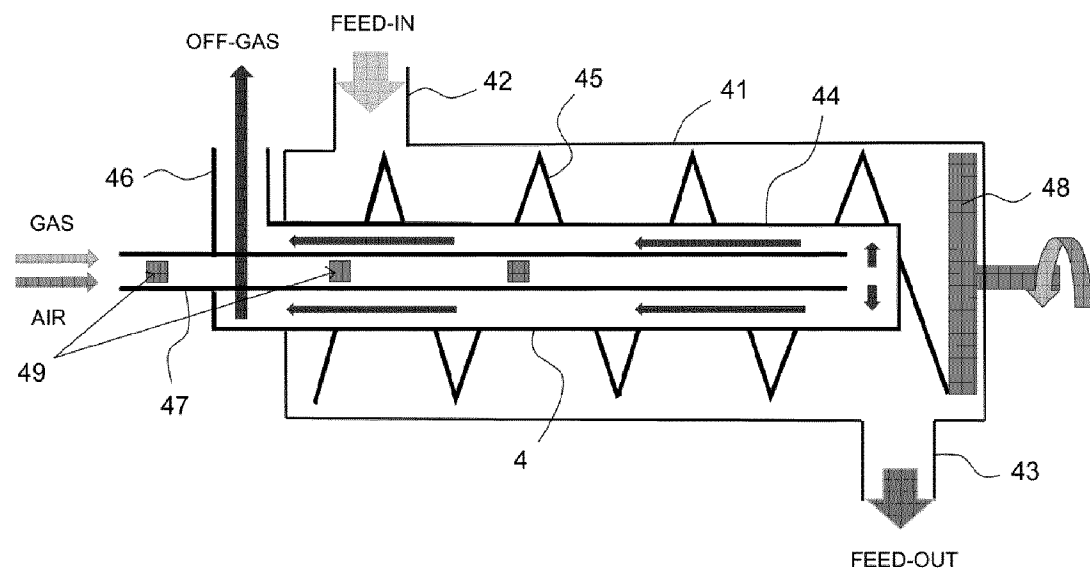
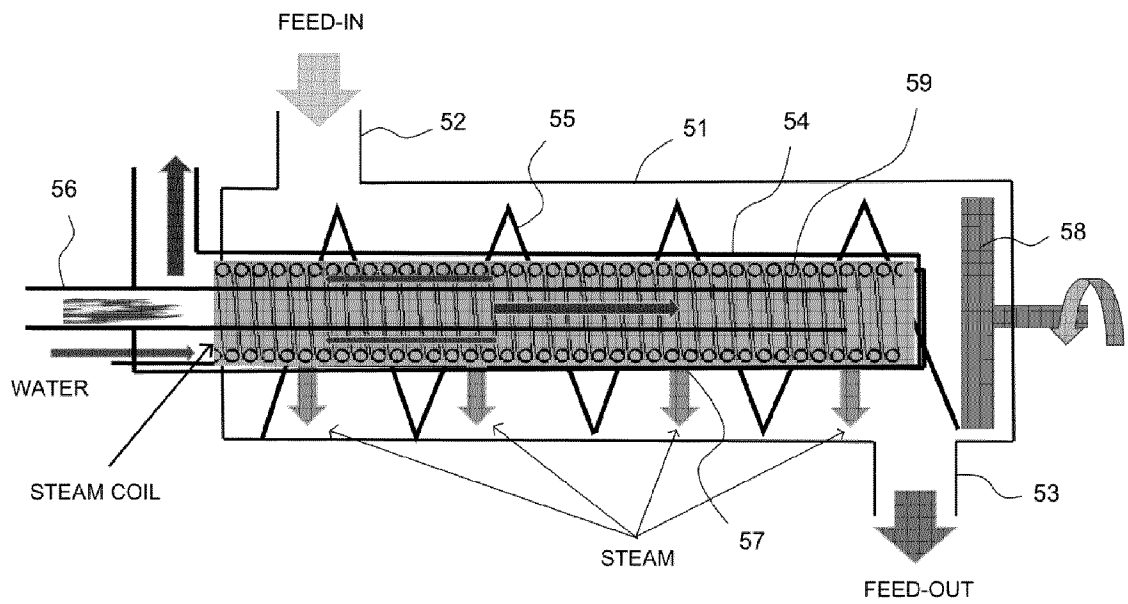
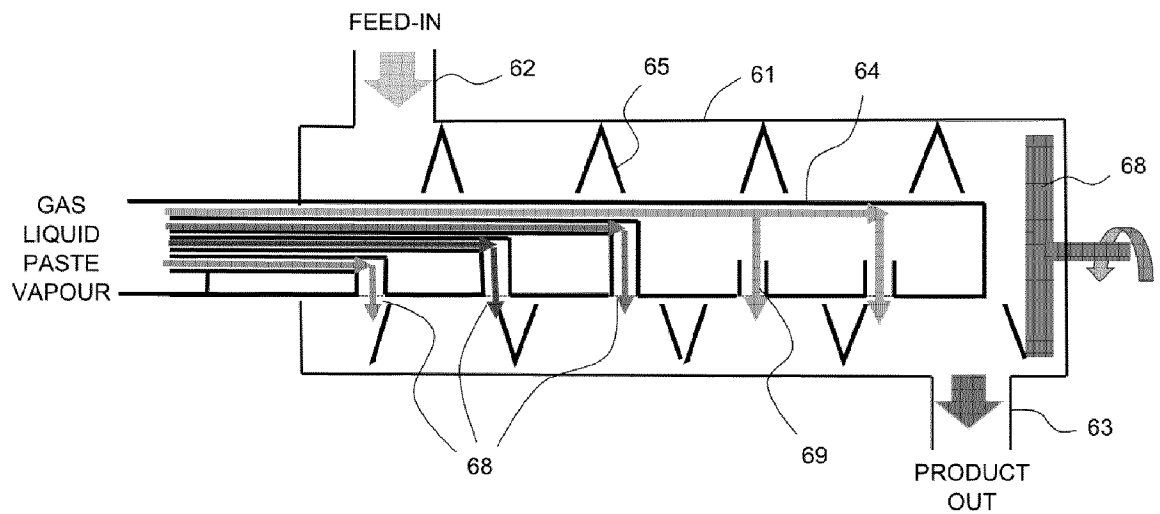


Fig. 5

**Fig. 6****Fig. 7**

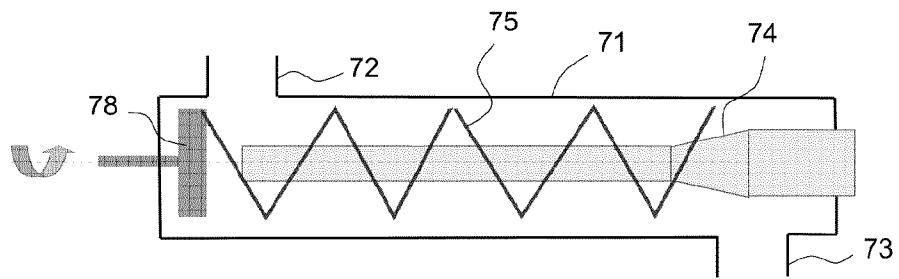


Fig. 8a

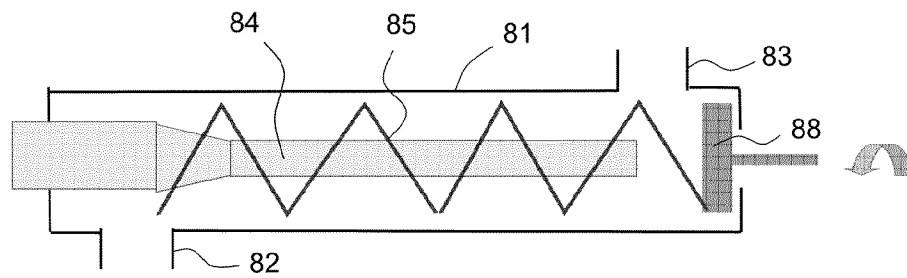


Fig. 8b

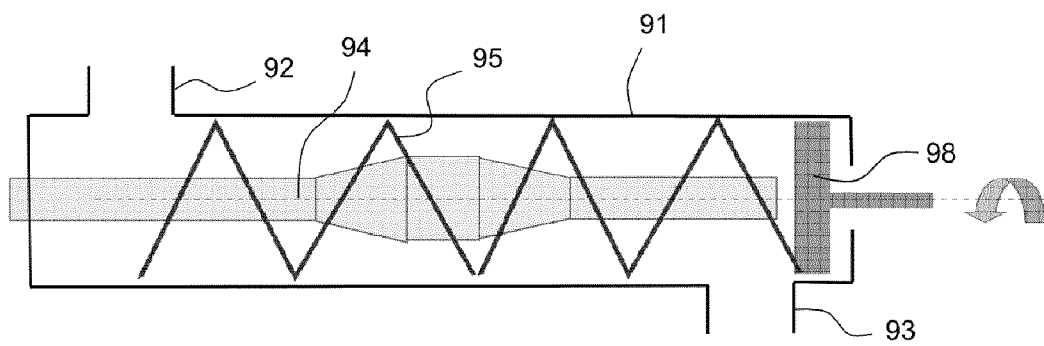


Fig. 8c

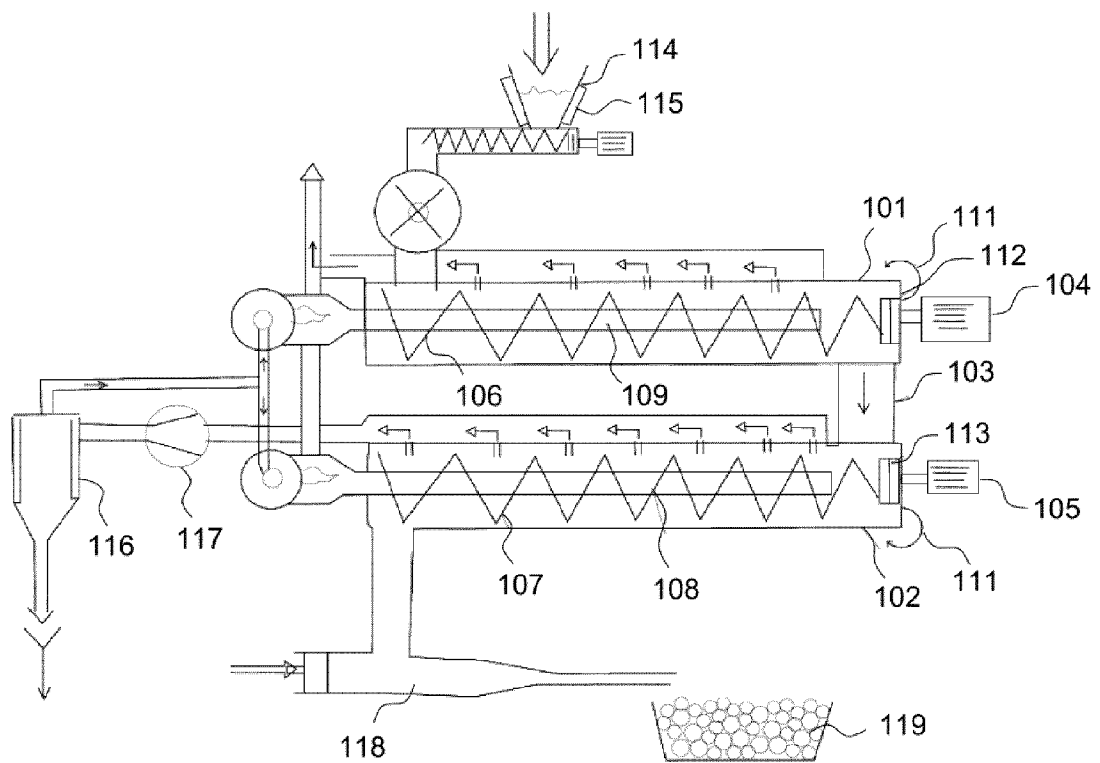


Fig. 9

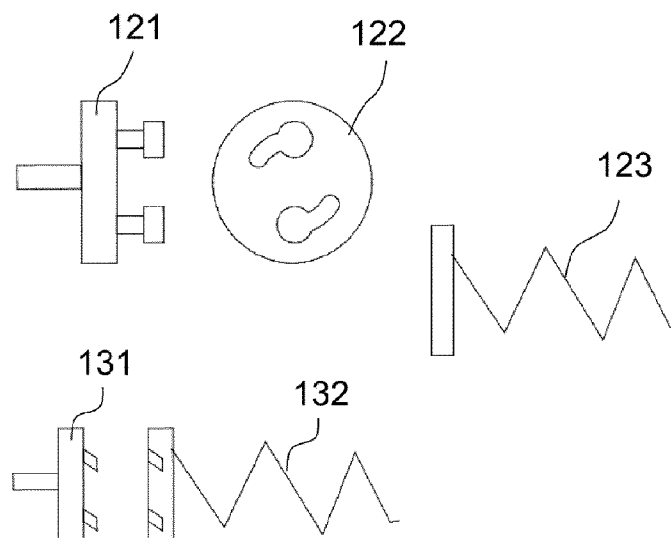


Fig. 10

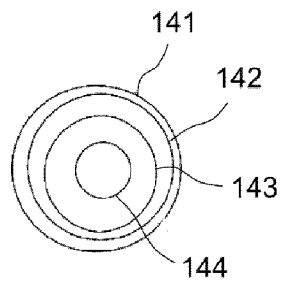


Fig. 11a

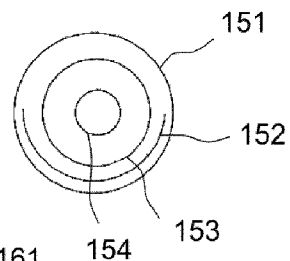


Fig. 11b

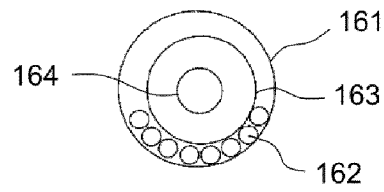


Fig. 11c

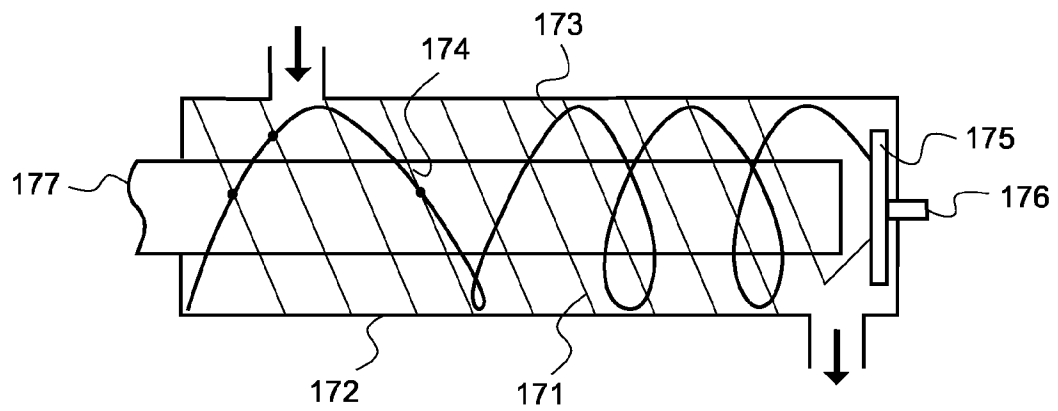


Fig. 12

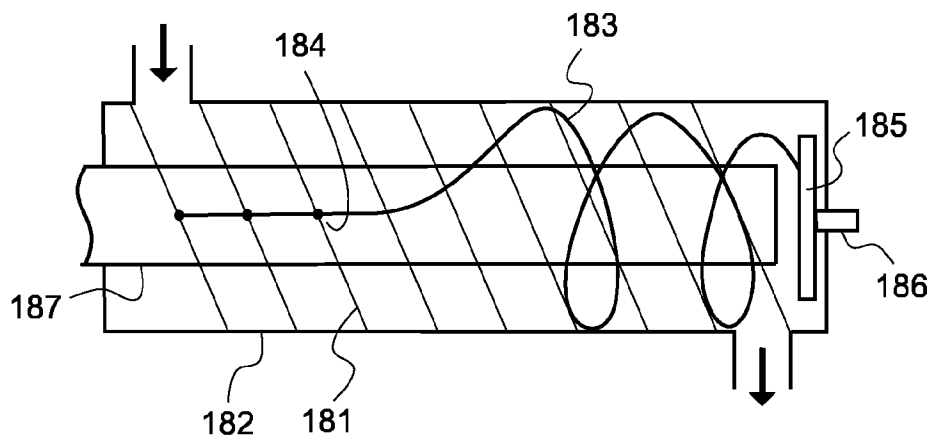


Fig. 13

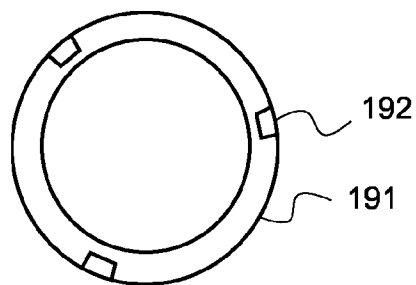


Fig. 14a

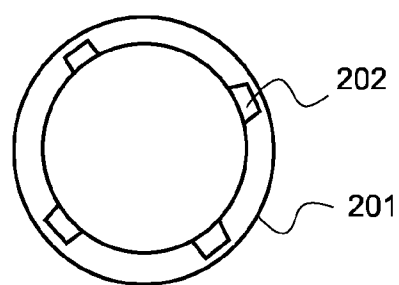


Fig. 14b

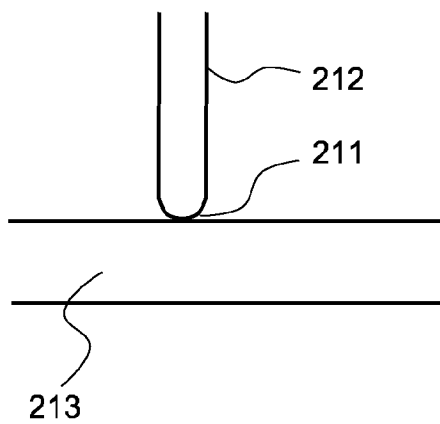


Fig. 15

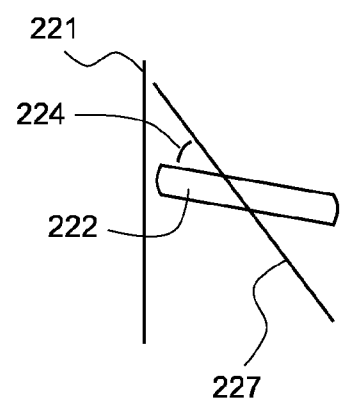


Fig. 16

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2014/057555

A. CLASSIFICATION OF SUBJECT MATTER

INV. C10L5/44 C10L9/08 B01J8/08 B01J8/10
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 B01J C10B B65G C02F 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)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	KR 2003 0038288 A (JO EUN JU [KR]) 16 May 2003 (2003-05-16) cited in the application claims 1-4 figure 7	1-30
X	----- US 5 810 470 A (GARRANT JEAN [FR] ET AL) 22 September 1998 (1998-09-22) cited in the application column 2, lines 7-65 figure 1	1-30
A	----- US 4 778 881 A (NIEUWENHUIS HERMANUS J W [NL] ET AL) 18 October 1988 (1988-10-18) column 3, lines 40-48 column 3, line 66 - column 4, line 4 figures 1,2 ----- -/--	1-30



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

6 August 2014

Date of mailing of the international search report

18/08/2014

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Authorized officer

Baumlin, Sébastien

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2014/057555

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2004/079262 A1 (HORNUNG ANDREAS [DE] ET AL) 29 April 2004 (2004-04-29) paragraphs [0014] - [0016], [0030] figures 1,7 -----	1-30
A	WO 2012/100247 A2 (TUCKER JERRY [US]; TUCKER NATHAN ROBERT [US]) 26 July 2012 (2012-07-26) paragraphs [0001] - [0004], [0036] figure 3 -----	1-30
A	WO 02/062683 A1 (DUNBRIAR INVEST LTD; LINDH PAUL [SE] DUNBRIAR INVEST LTD [TC]; LINDH P) 15 August 2002 (2002-08-15) cited in the application claims 1-13 figures 1,3 -----	1-30
A	US 3 688 992 A (SCHALLIS ALVIN) 5 September 1972 (1972-09-05) column 2, lines 28-44 column 3, lines 8-26 -----	1-30
A	US 2011/212012 A1 (MCALISTER ROY EDWARD [US]) 1 September 2011 (2011-09-01) paragraphs [0035] - [0047], [0087] - [0089] figures 2,3,9 -----	1-30
A	US 2012/116135 A1 (GONG KENING [US] ET AL) 10 May 2012 (2012-05-10) claims 1-16 -----	1-30

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2014/057555

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
KR 20030038288 A	16-05-2003	NONE	
US 5810470 A	22-09-1998	AU 7230494 A BG 99998 A CA 2165428 A1 CZ 9600032 A3 EG 20403 A EP 0707512 A1 FR 2707204 A1 MY 130058 A PL 312459 A1 RU 2123379 C1 SK 696 A3 US 5810470 A WO 9501830 A1	06-02-1995 31-05-1996 08-01-1995 14-08-1996 28-02-1999 24-04-1996 13-01-1995 31-05-2007 29-04-1996 20-12-1998 08-01-1997 22-09-1998 19-01-1995
US 4778881 A	18-10-1988	AT 42106 T AU 583087 B2 CA 1279316 C DE 3662789 D1 DK 28586 A EP 0190779 A1 ES 8706040 A1 FI 860309 A IE 58811 B1 JP 2849592 B2 JP S61180796 A NL 8500191 A NZ 214903 A US 4778881 A	15-04-1989 20-04-1989 22-01-1991 18-05-1989 25-07-1986 13-08-1986 16-08-1987 25-07-1986 17-11-1993 20-01-1999 13-08-1986 18-08-1986 29-02-1988 18-10-1988
US 2004079262 A1	29-04-2004	AT 272823 T AU 1712202 A AU 2002217122 B2 BR 0116689 A CA 2432014 A1 CN 1481496 A DE 60104724 D1 DE 60104724 T2 EP 1217318 A1 EP 1354172 A1 ES 2225414 T3 HU 226552 B1 JP 4413494 B2 JP 2004516447 A KR 20030072366 A MX PA03005524 A US 2004079262 A1 WO 0250484 A1 ZA 200305093 A	15-08-2004 01-07-2002 15-06-2006 21-10-2003 27-06-2002 10-03-2004 09-09-2004 11-08-2005 26-06-2002 22-10-2003 16-03-2005 30-03-2009 10-02-2010 03-06-2004 13-09-2003 14-10-2004 29-04-2004 27-06-2002 30-06-2004
WO 2012100247 A2	26-07-2012	EP 2665803 A2 US 2013299333 A1 WO 2012100247 A2	27-11-2013 14-11-2013 26-07-2012
WO 02062683 A1	15-08-2002	AT 358086 T EP 1365978 A1 SE 0100281 A	15-04-2007 03-12-2003 08-08-2002

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2014/057555

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
		WO 02062683 A1	15-08-2002
US 3688992	A 05-09-1972	DE 2117689 A1	28-10-1971
		FR 2089656 A5	07-01-1972
		GB 1342651 A	03-01-1974
		JP S55788 A	07-01-1980
		JP S5753364 B1	12-11-1982
		JP S6017321 B2	02-05-1985
		US 3688992 A	05-09-1972
US 2011212012	A1 01-09-2011	CN 102906227 A	30-01-2013
		EP 2534224 A2	19-12-2012
		US 2011212012 A1	01-09-2011
		WO 2011100695 A2	18-08-2011
US 2012116135	A1 10-05-2012	NONE	