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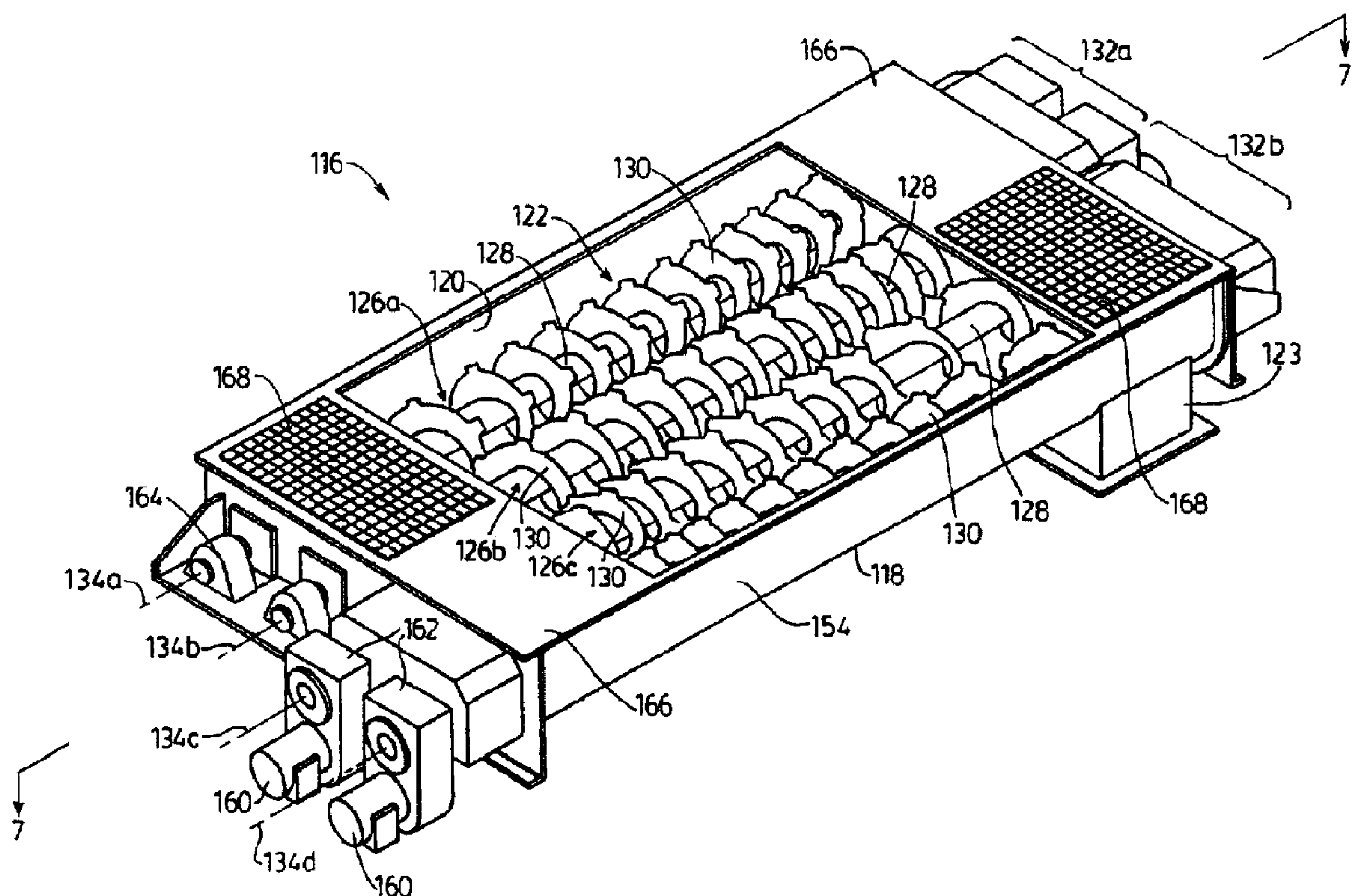
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(54) Titre : METHODE ET APPAREILLAGE DE TRANSPORT DE PRODUITS DE DEPART CELLULOSIQUES

(54) Title: METHOD AND APPARATUS FOR CONVEYING A CELLULOSIC FEEDSTOCK



(57) Abrégé/Abstract:

A method and apparatus for conveying a cellulosic feedstock are disclosed. The apparatus, such as a holding tank, has a passage. At the outlet to the passage, a conveyance member is provided to convey the cellulosic feedstock laterally across the outlet. The conveyance member, e.g., at least one screw conveyor, may have a variable pitch along its length. The method comprises passing the cellulosic feedstock through an impregnation chamber to an outlet of the impregnation chamber; passing the cellulosic feedstock from the outlet of the impregnation chamber to an inlet of a holding tank; passing the cellulosic feedstock downwardly through the holding tank; maintaining a generally constant residence time in the holding tank; and subsequently subjecting the cellulosic feedstock to a hydrolysis process.



ABSTRACT

A method and apparatus for conveying a cellulosic feedstock are disclosed. The apparatus, such as a holding tank, has a passage. At the outlet to the passage, a conveyance member is provided to convey the cellulosic feedstock laterally across the outlet. The conveyance member, e.g., at least one screw conveyor, may have a variable pitch along its length. The method comprises passing the cellulosic feedstock through an impregnation chamber to an outlet of the impregnation chamber; passing the cellulosic feedstock from the outlet of the impregnation chamber to an inlet of a holding tank; passing the cellulosic feedstock downwardly through the holding tank; maintaining a generally constant residence time in the holding tank; and subsequently subjecting the cellulosic feedstock to a hydrolysis process.

Title: METHOD AND APPARATUS FOR CONVEYING A CELLULOSIC
FEEDSTOCK

FIELD

The invention relates to a method and apparatus for obtaining and conveying a cellulosic feedstock, which may be used for the subsequent production of a fermentable sugar stream from the cellulose and hemicellulose in the cellulosic feedstock wherein the fermentable sugar stream may be used for subsequent ethanol production. More specifically, the invention relates to a method and apparatus for withdrawing one or more feedstock stream from a holding tank.

BACKGROUND

Several processes for the production of ethanol are known. Generally, the production of fuel ethanol involves the fermentation of sugars with yeast. Typically, the sugars are derived from grains, such as corn and wheat. The starches in the grains are subjected to enzymatic hydrolysis in order to produce the sugars, which are then subjected to fermentation to produce ethanol.

Plant materials are a significant source of fermentable sugars, such as glucose that can be transformed into biofuels. However, the sugars in plant materials are contained in long polymeric chains of cellulose and hemicellulose. Utilizing current fermentation processes, it is necessary to break down these polymeric chains into monomeric sugars, prior to the fermenting step.

Recently, processes have been developed for utilizing cellulosic feedstock, such as corncobs, straw, and sawdust, to produce sugars for ethanol fermentation. Such processes typically comprise pre-treating the feedstock to increase the accessibility of the cellulose to hydrolysis enzymes, and subjecting the cellulose to cellulase enzyme systems to convert the cellulose into glucose.

Methods of converting plant biomass into fermentable sugars are known in the art and in general comprise two main steps: a pre-treatment step to

activate the plant structure, and an enzymatic or chemical hydrolysis step to convert the polymeric chains of cellulose and hemicellulose into monomeric sugars. Several approaches have been used for the pre-treatment step, e.g., autohydrolysis, acid hydrolysis, ammonia activation, kraft pulping, organic solvent pulping, hot water pre-treatment, ammonia percolation, lime pre-treatment, caustic soda pulping, or alkali peroxide pre-treatment. Early pre-treatment steps included grinding or milling the feedstock into a powder, which was then mixed with water to form a slurry.

More recently, solvent based pre-treatments, alkali pre-treatments, and acidic pre-treatments have also been described. PCT publication WO/2007/009463 to Holm Christensen describes an alternate pre-treatment, which does not involve the addition of acids, bases, or other chemicals. This pre-treatment process involves soaking the cellulosic material in water, conveying the cellulosic material through a heated and pressurized reactor, and pressing the cellulosic material to produce a fiber fraction and a liquid fraction. After pressing the cellulosic material, the cellulosic material is exposed to hydrolysis enzymes.

Each pre-treatment technology has a different mechanism of action on the plant structure, inducing either physical and/or chemical modifications. However, the main objective of the pre-treatment is to provide accessibility of the plant material to the enzymes.

SUMMARY

The commercial viability of a hydrolysis process is dependent on the character of the feedstock provided to the hydrolysis unit. Typically, this requires that a feedstock is activated such that a significant portion (e.g., greater than 75%) of the cellulose and hemicellulose of the feedstock is accessible to hydrolysis enzymes. If such an activated feedstock is provided to an enzymatic hydrolysis unit, then at least 60%, preferably more than 75% and more preferably over 90% of the cellulose and hemicelluloses may be converted to monomeric

sugars. This sugar rich process stream may subsequently be subjected to fermentation to produce an alcohol stream. The alcohol stream from the fermentation stage (i.e., the raw alcohol stream) may have an ethanol content of about 3-22% v/v, preferably about 5-15% and more preferably more about 8-12%.

An activated feedstock for enzymatic hydrolysis is preferably prepared by autohydrolysis, which is preferably conducted in a steam explosion reactor also known as a hydrolyzer (also known as a digester). Autohydrolysis is a process of breaking down hemicellulose and cellulose by exposure to high temperatures, steam and pressure, sometimes in the presence of an added chemical agent, such as an organic or inorganic acid, e.g., sulphuric acid. When performed in the presence of an added acid, the reaction is known as an acid hydrolysis.

During autohydrolysis, the degree of polymerization of cellulose and hemicellulose may be reduced from about 10,000 to about 1,500-1,000. This process is preferably carried out above the glass transition temperature of lignin (120 - 160°C). Depending upon the severity of the reaction, degradation products may be produced, such as furfural, hydroxyl-methylfurfural, formic acid, levulinic acid and other organic compounds.

During a steam explosion treatment (more commonly called autohydrolysis if no externally added catalyst), a cellulosic feedstock is subjected to elevated heat (e.g., 180°C to 220°C) and pressure (e.g., 130 psig to 322 psig) optionally in the presence of suitable chemicals (e.g., organic/ and/or inorganic acids, ammonia, caustic soda, sulfur dioxide, solvents etc.) in a pressurized vessel. Preferably, external chemical addition is not utilized; in which case, the only catalyst that may be present may be acetic acid that is generated in situ. The treated cellulosic feedstock is then released from the pressurized vessel such that the pressure is rapidly reduced (e.g., 1 second or less). The biomass may exit the hydrolyzer into a reduced pressure, preferably atmospheric pressure and, more preferably into a vacuum. The rapid decrease in pressure results in

the biomass separating into individual fibers or bundles of fiber. This step opens the fiber structure and increases the surface area. The lignin remains in the fiber along with cellulose and residual hemicellulose. Accordingly, the explosive release of pressure, combined with the high temperature and pressure treatment results in the physicochemical modification of the cellulosic feedstock that is then suitable for feeding to an enzymatic hydrolysis unit.

In order for the steam explosion process to be able to produce an activated feedstock that is capable of producing such a sugar rich process stream, the temperature and moisture level of the cellulosic feedstock that is fed to a steam explosion reactor preferably is relatively uniform and preferably has a temperature from about 50 to about 70°C, and more preferably 50 - 65°C and a moisture content from about 30 to about 60 wt % (preferably 45 to about 55 wt %). Moisture content is the quantity of water contained in a material, and on a weight basis, is the weight of water in the material divided by the mass of the material.

Embodiments of the present invention provide a method and apparatus for withdrawing a cellulosic feedstock from a vessel by actively withdrawing feedstock from different portions of the outlet of a vessel and, preferably, withdrawing a feedstock evenly from across the outlet. An advantage of this design is that a generally uniform residence time of the feedstock in the vessel may be achieved. For example, the variance of the residence time may be up to 5 minutes, preferably, less than 3 minutes and more preferably less than 2 minutes. Accordingly, the tendency of the portion of a feedstock that is adjacent a heated surface in the vessel, such as a surface in thermal contact with a heating jacket, to be degraded by overheating may be reduced and, preferably, eliminated.

Alternately, or in addition, embodiments of the present invention provide a method and apparatus for withdrawing a cellulosic feedstock from a vessel in a direction transverse to the direction of travel of the material through the vessel. Accordingly, if the vessel is oriented such that they passage

therethrough is generally vertical, the feedstock is withdrawn generally horizontally. A plurality of feedstock streams, each of which may be conveyed in a different direction may be obtained.

According to a first broad aspect, a holding tank apparatus for preparing a cellulosic feedstock is provided. The holding tank apparatus comprises at least one sidewall defining a volume having an upper portion and a lower portion. At least one inlet is provided adjacent the upper portion, and at least one outlet is provided adjacent the lower portion, at an elevation below the inlet. At least one screw conveyor is provided for conveying the cellulosic feedstock laterally across the outlet. The at least one screw conveyor has a variable pitch along its length. Providing the at least one screw conveyor with a variable pitch along its length may allow for a generally equal amount of cellulosic feedstock to be withdrawn from all portions of the outlet.

In some embodiments, the at least one screw conveyor has a first end and a second end, and the pitch at the first end differs from the pitch at the second end. In some further embodiments, the at least one screw conveyor comprises a first region having a first range of pitch, and a second region having a second range of pitch. In yet further embodiments, the at least one screw conveyor comprises an intermediate region between the first region and the second region, and the intermediate region has a third range of pitch between the first range of pitch and the second range of pitch.

In some embodiments, the at least one screw conveyor has a first end and a second end, and the pitch decreases from the first end to the second end and, preferably, varies at a constant rate between the first end and the second end.

In some embodiments, the outlet defines a plurality of portions and the pitch varies such that approximate equal portions of feedstock are withdrawn from each portion of the outlet.

In some embodiments, the at least one screw conveyor comprises a plurality of screw conveyors and at least one of the screw conveyors conveys

the cellulosic feedstock in a first direction and at least one of the screw conveyors conveys the cellulosic feedstock in a second direction. In a further embodiment, the first direction and the second direction are substantially opposite.

In some embodiments, the at least one screw conveyor comprises a plurality of screw conveyors and at least two adjacent two screw conveyors have a length and convey the cellulosic feedstock in a first direction and the pitch of the screw conveyors at any location along the length of the screw conveyors is essentially the same.

In some embodiments, the apparatus comprises a plurality of screw conveyors having a length, and a first pair of the screw conveyors conveys cellulosic feedstock in the first direction, and a second pair of the screw conveyors conveys cellulosic feedstock in the second direction.

In some such embodiments, the pitch of the first pair of screw conveyors at any location along the length is essentially the same and the pitch of the second pair of screw conveyors at any location along the length is essentially the same. In some further embodiments, the first pair of screw conveyors conveys cellulosic feedstock in the first direction, and the second pair of screw conveyors conveys the cellulosic feedstock in a second direction opposite to the first direct, and the pitch of the first pair of screw conveyors is a mirror image of the pitch of the second pair of the screw conveyors.

In some embodiments, the first pair of screw conveyors is rotatable in a first direction, and the second pair of screw conveyors is rotatable in a second direction opposite to the first direction.

In some embodiments the at least one screw conveyor extends across all of the outlet.

In some embodiments, the apparatus further comprises a heating jacket provided on at least a portion of the apparatus. Such embodiments may be advantageous because the heating jacket may elevate or maintain the

temperature of the cellulosic feedstock, which may render the cellulosic feedstock further accessible to auto hydrolysis, preferably followed by enzymes hydrolysis.

In some embodiments, the lower portion of the holding tank has a greater cross sectional area than the upper portion of the holding tank. Such embodiments may be advantageous because cellulosic material may be prevented from adhering or sticking to the sidewalls as the cellulosic material passes through the holding tank. Accordingly, each portion of cellulosic feedstock that passes through the holding tank may have essentially the same residence time in the volume.

In some embodiments, the sidewalls comprise a first sidewall and a second sidewall opposed to the first sidewall, and the first and second sidewalls diverge relative to each other from the upper portion to the lower portion.

In some embodiments, the sidewalls comprise a third sidewall and a fourth sidewall opposed to the third sidewall, and the third and fourth sidewalls extend between the first and second sidewalls, and the third and fourth sidewalls diverge relative to each other from the upper portion to the lower portion.

In another broad aspect, a method of preparing a cellulosic feedstock for ethanol production is provided. The method comprises passing the cellulosic feedstock through an impregnation chamber to an outlet of the impregnation chamber; passing the cellulosic feedstock from the outlet of the impregnation chamber to an inlet of a holding tank, the holding tank having an outlet; passing the cellulosic feedstock downwardly through the holding tank; maintaining a generally constant residence time in the holding tank; and subsequently subjecting the cellulosic feedstock to a downstream hydrolysis process.

In some embodiments, the method further comprises maintaining a temperature in the holding tank between about 50°Celsius and about 75°Celsius.

In some embodiments, the method further comprises maintaining a variance of the residence time of each portion of the amount of up to 5 minutes.

In some embodiments, the method further comprises maintaining a residence time in the holding tank from about 10 to about 45 minutes.

In some embodiments, the method further comprises conveying the cellulosic feedstock laterally across an outlet of the holding tank. In some such embodiments, the cellulosic feedstock is actively withdrawn from essentially the entirety of the outlet. Further, in some such embodiments a generally equal amount of cellulosic feedstock is withdrawn from each portion of the outlet. Further, in some such embodiments, the cellulosic feedstock is conveyed in at least two different lateral directions.

In some embodiments, a screw conveyor having different pitches is utilized to convey the cellulosic feedstock laterally across the outlet of the holding tank.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other advantages of the present invention will be more fully and particularly understood in connection with the following description of the preferred embodiments of the invention in which:

Figure 1 is a perspective illustration of an embodiment of a holding tank of the present invention, showing an impregnation chamber positioned upstream from the holding tank;

Figure 2 is a perspective illustration of the impregnation chamber of Figure 1;

Figure 3 is a top cutaway view of the impregnation chamber of Figure 1;

Figure 4 is a cross section taken along line 4-4 in Figure 2;

Figure 5 is a cross section taken along line 5-5 in Figure 1;

Figure 6 is a perspective view of an embodiment of housing of the present invention, shown removed from a holding tank;

Figure 7 is a cross-section taken along line 7-7 in Figure 6;

Figure 8 is a top view of the housing of Figure 6;

Figure 9 is a top view of an alternate embodiment of a housing of the present invention; and,

Figure 10 is a cross-section taken along line 10-10 in Figure 1.

DETAILED DESCRIPTION

Embodiments of the present invention provide enhanced uniformity of residence time of the feedstock in a holding tank. In particular, despite withdrawing the feedstock laterally with respect to the direction of flow through the holding tank, a generally uniform residence time for all portions of the feedstock that are concurrently withdrawn from the holding tank may be obtained.

An embodiment of an apparatus of the present invention is shown in Figures 1-10. It will be appreciated that although the method is described with reference to the apparatus and vice versa, the method may be carried out with an alternate apparatus, and the apparatus may be used according to an alternate method. Furthermore, although the method is described as a continuous process, it will be appreciated that the method may be carried out as a semi-continuous or batch process.

The cellulosic feedstock is preferably a lignocellulosic feedstock. A lignocellulosic feedstock is derived from plant materials. As used herein, a "lignocellulosic feedstock" refers to plant fiber containing cellulose, hemicellulose and lignin. In some embodiments, the feedstock may be derived from trees, preferably deciduous trees such as poplar (e.g., wood chips). Alternately or in addition, the feedstock may also be derived from agricultural residues such as,

but not limited to, corn stover, wheat straw, barley straw, rice straw, switchgrass, sorghum, bagasse, rice hulls and/or corn cobs. Preferably, the lignocellulosic feedstock comprises agricultural residues and wood biomass, more preferably wood biomass and most preferably deciduous. The applicants contemplate other sources of plant materials comprising cellulose, hemicellulose and/or lignin, such as algae, for use in deriving cellulosic feedstocks and any of those may be used. The lignocellulosic feedstock is preferably cleaned, e.g., to remove ash, silica, metal strapping (e.g., from agricultural products), stones and dirt. The size of the components of the lignocellulosic feedstock may also be reduced. The size of the components of the feedstock may be from about 0.05 to about 2 inches, preferably from about 0.1 to about 1 inch, and more preferably from about 0.125 to about 0.5 inches in length. For example, the cellulosic feedstock may comprise fibers, e.g., chopped straw, of a length of between about 0.16 inches and about 0.28 inches. Any process machinery that is able to crush, grind or otherwise decrease the particle size may be utilized.

The feedstock is preferably treated with water so as to have a moisture content upon entry to holding tank 100 of between about 30 and about 60 preferably between about 45 and about 55 wt %. For example, referring to Figures 1 and 2, an embodiment of a holding tank apparatus 100 of the present invention is shown wherein the holding tank 100 is positioned downstream from a water impregnation reactor such as impregnation chamber 10, which is preferably used to pre-treat the feedstock prior to the feedstock entering holding tank 100. Impregnation chamber 10 is preferably configured to pre-treat the cellulosic feedstock, for example by moistening and/or heating the cellulosic feedstock.

A preferred impregnator 10 is exemplified in Figures 2-4. As shown therein, in some embodiments, an impregnator feeder 30, namely a feeder that conveys feedstock into impregnation chamber 12, is preferably positioned upstream of mixing or impregnation chamber 12. Feeder 30 may be of any design. Preferably, feeder 30 is of a design that inhibits, and preferably prevents, the flow of moisture upstream of feeder 30. For example, a rotating valve or the

like may be provided to segment such upstream flow. Preferably impregnation feeder is a screw feeder comprising a motor 32 drivingly connected to a screw or auger 34 positioned below an inlet, such as via a transmission or gear reduction assembly provided in housing 36. The shaft on which screw 34 is provided may be rotatably mounted in housing 38 such that auger 34 is a cantilevered plug screw conveyor. Accordingly, feeder 30 produces a plug of material that prevents upstream migration of moisture. The plug may be conveyed into inlet housing 40 that is mounted to impregnation chamber 12. The feedstock may then pass downwardly into impregnation chamber 12.

Impregnator 10 may comprise an inlet 42 positioned below inlet housing 40, one or more conveyance members 14 for urging the cellulosic feedstock along the length of chamber 12, one or more moisture injection ports 16, which may be provided on paddles 20 of conveyance member 14 and/or inner wall 22 of impregnator 10, for injecting moisture into the cellulosic feedstock one or more heating jackets 18 provided outward of inner wall 22 for heating the cellulosic feedstock, and an outlet 24. Heating jacket 18 may comprise an outer wall 26 spaced from inner wall 22 to define a passage 28 through which a heated fluid, e.g. water, may pass.

As exemplified in Figure 2, one or more conduits 54 may convey water to a plurality of branch conduits 56 extending to different locations on the upper portion of chamber 12. The end of these conduits are in fluid flow communication with the interior of chamber 12, via, e.g., a moisture addition member such as a nozzle or an open ended pipe or the like.

As exemplified, conveyance members 14 are rotatably mounted in chamber 12 and are drivenly connected to a motor 46. As exemplified, motor 46 is drivingly connected to conveyance members 14 via a transmission or gear reduction assembly provided in housing 48. The gear reduction assembly may be drivingly connected to ends 50 of conveyance members 14 that are positioned inside housing 52.

In order to prevent material stagnating in impregnator 10, impregnator 10 may have a bottom wall 44 that has two or more portions each of which has a conveyance member 14 associated therewith. Bottom wall 44 and conveyance member 14 are preferably configured such that bottom wall 44 is swept as conveyance member 14 rotates. For example, as exemplified in Figure 4, bottom wall 24 may be scallop shaped, e.g., have two inverted arches or troughs. Further details regarding various embodiments of optional impregnation chamber 10 may be found in the co-pending U.S. Patent Application filed on July 29, 2008 and published as U.S. Patent Publication No. 2010/0028089 A1. In alternate embodiments, impregnation chamber 10 may pre-treat the cellulosic feedstock in another manner, and the invention is not limited in this regard.

After the cellulosic feedstock is optionally pre-treated in impregnation chamber 10, it is directed to holding tank apparatus 100, e.g., via outlet passage 58 that is downstream from outlet 24 of chamber 12, where it is held or contained for a residence time, such that for example, moisture added in impregnation chamber 10 has sufficient time to penetrate into the feedstock so that the feedstock is ready for downstream processing. Alternately, or in addition, the feedstock may require additional time for all portions of the feedstock to be raised to a predetermined temperature that is suitable for downstream processing. Alternately, the feedstock entering holding tank 100 may be at the predetermined conditions for downstream processing and holding tank is used as a reservoir to hold prepared feedstock such that downstream processes may operate on a continuous basis. From holding tank 100, the cellulosic feedstock may be directed to one or more hydrolysis reactors, preferably one or more autohydrolysis reactors followed by one or more enzymatic hydrolysis reactors (not shown) positioned downstream from the holding tank apparatus 100 such that the cellulose may be hydrolyzed to produce sugars that are suitable for fermentation to ethanol.

As exemplified in Figures 1 and 5, holding tank 100 is oriented such that the passage through holding tank 100 preferably extends generally downwardly and the passage therethrough is preferably configured so as to

reduce, and more preferably essentially prevent, bridging of feedstock in holding tank 100. Further, the passage from impregnator 10 to holding tank 100 preferably extends generally downwardly. Accordingly, it is preferred that the passage through holding tank 100 extends generally downwardly and that the passage has a greater cross sectional area at the lower end than the upper end. More preferably, the cross sectional area continually increases in the downward direction. This may be achieved by constructing the passage of the holding tank with one or more walls that diverge in the downward direction.

If the feedstock passing downwardly through holding tank 100 interlocks, it may form a blockage by a process known as bridging. The blockage may extend all the way across the passage in holding tank 100 thereby preventing downward movement of feedstock and causing a gap in the supply of feedstock to the downstream process unit. Alternately, it may block only part of the passage. In any event, intervention would then be required to remove the blockage. The interruption of feedstock delivery to the downstream process unit could require part of a plant to be shut down while the blockage is removed thereby reducing throughput and also requiring the plant to be brought back to steady state operating conditions once the blockage is cleared. Accordingly, the holding tank may require monitoring to permit intervention at an early stage should bridging occur. By increasing the cross sectional area in the downstream direction, the tendency of the feedstock to form a blockage of the passage is reduced and may be eliminated.

As exemplified in Figures 5 and 10, holding tank 100 comprises at least one sidewall, which defines a volume or passage 104. In the embodiment shown, holding tank apparatus 100 comprises four sidewalls, namely front wall 102a, and a spaced apart opposed rear wall 102b, and a side wall 102c, and a spaced apart opposed side wall 102d, and further comprises a top wall 103. Accordingly, passage 104, which is defined by sidewalls 102a, 102b, 102c and 102d, is rectangular in transverse section. In other embodiments, holding tank apparatus 100 may comprise, for example, a single rounded sidewall so as to

have a transverse section that is circular, elliptical or the like. It will be appreciated that any other transverse section may be utilized.

Passage 104 is preferably longitudinally extending, for example along axis 105, and comprises an upper portion 106, and a lower portion 108. Passage 104 preferably extends vertically. However passage may extend generally vertically (i.e., at an angle to the vertical such that feedstock will flow downwardly therethrough under the force of gravity). In some embodiments, passage 104 may have a length along axis 105 of between about 5 ft and about 20 ft.

An inlet 110 is provided adjacent upper portion 106, and an outlet 112 is provided adjacent lower portion 108, at an elevation below the inlet 110. In the embodiment shown, inlet 110 is defined by an opening in top wall 103, and outlet 112 is defined by the lower ends 114 of sidewalls 102a-102d. It will be appreciated that inlet 110 may comprise the entirety of the top end of holding tank 100 and accordingly, a top wall 103 may not be required. It will be appreciated that in the preferred embodiment, no lower surface is provided for passage 104 and that the lower end of passage 104 is open. Accordingly, feedstock may flow downwardly through passage 104 unimpeded until it encounters feedstock stored in holding tank 100 or until it encounters housing 116. As exemplified, inlet 110 is in fluid communication with and receives cellulosic feedstock from outlet 24 of impregnation chamber 10 (e.g. it is downstream of outlet conduit 58), and outlet 112 is preferably in fluid communication with and directs cellulosic feedstock to one or more autohydrolysis reactors (not shown).

Referring still to Figure 5, in the preferred embodiment, lower end 108 of passage 104 has a greater cross sectional area than upper end 106 of passage 104. That is, a transverse cross section taken through passage 104 adjacent outlet 112 has a greater cross sectional area than a transverse section taken through passage 104 adjacent inlet 110. For example, the cross sectional area taken adjacent outlet 112 may have an area of between about 40 ft² and

about 60 ft², and the cross sectional area taken adjacent inlet 110 may have an area of between about 20 ft² and about 40 ft².

The sidewalls may be configured in a variety of ways in order to provide lower end 108 with a greater cross sectional area than upper end 106. In the embodiment shown, sidewall 102a and sidewall 102b are opposed to each other, and sidewall 102c and sidewall 102d are opposed to each other, and each of the sidewalls diverge from axis 105 going from inlet 110 to outlet 112. Accordingly, passage 104 is substantially frusto-pyramidal, and lower end 108 has a greater cross sectional area than upper end 106. In an alternate embodiment, sidewalls 102a and 102b may extend substantially parallel to axis 105, and sidewalls 102c and 102d may diverge from axis 105. In yet another alternate embodiment, holding tank apparatus 100 may comprise a single rounded sidewall defining a frustoconical passage 104. In yet another embodiment, sidewalls 102a-102d may be stepped. It is preferred that the sidewalls continually diverge and that they continually diverge for the entire length of passage 104 as exemplified. Preferably, they diverge at an angle A from the vertical from about 1° to about 20°, preferably from about 2° to about 5°. It will also be appreciated that inner surface 138 of the sidewalls are preferably smooth and clear of projections that could be a source causing bridging to occur.

Providing lower portion 108 with a greater cross sectional area than upper portion 106 may aid in preventing cellulosic material from adhering or sticking to the sidewalls as the cellulosic material passes through holding tank apparatus 100. Accordingly, each portion of cellulosic feedstock that passes through holding tank 100 may have essentially the same residence time in passage 104.

In alternate embodiments, lower portion 108 of volume 104 may not have a greater cross sectional area than upper portion 106 of volume 104. For example, each of sidewalls 102a-102d may extend essentially vertically and parallel to each other.

In some embodiments, the feedstock may travel directly downwardly to the next process unit, e.g. a steam explosion reactor. In such a

case, it is preferred the passage continually increase in cross sectional area (as opposed to using a hopper). However, it is preferred that the feedstock, after traveling downwardly through passage 104, is conveyed laterally (transverse to axis 105). Further, it is preferred that the feedstock is actively withdrawn from holding tank 104 instead of permitting the feedstock to passively exit therefrom. Accordingly holding tank 100 may further comprise or be provided with at least one conveyor adjacent outlet 112 that is configured to actively convey the cellulosic feedstock laterally across outlet 112 to withdraw the cellulosic feedstock from passage 104. Referring to Figures 5 to 8, in the embodiment shown, the at least one conveyor comprises a plurality of screw conveyors 126, which are housed in a housing 116. The conveyor may be any transport mechanism known in the art to actively transport feedstock laterally from outlet 112. For example, the conveyor may comprise an auger, a screw conveyor, tabbed flight screw with bars, or the like that extends transversely to axis 105.

In the embodiment shown, housing 116 comprises a base 118, sidewalls 120, and an open top 122. Open top 122 is preferably at least as large as outlet 112, and is in vertical registration with outlet 112, such that material passing through outlet 112 may pass directly downwardly through open top 122. It will be appreciated that in alternate embodiments, the sidewalls of passage 104 may provide the sidewalls of housing 116. That is, the sidewalls may extend beyond outlet 112. Accordingly, in such an embodiment, outlet 112 of passage 104 may not be defined by ends 114 of the sidewalls, and rather, may be defined by a portion of the sidewalls above ends 114.

Housing 116 comprises at least a first housing outlet, through which cellulosic feedstock conveyed by screw conveyors 126 exits housing 116. Cellulosic feedstock exiting the housing outlet(s) may pass into one or more conduits 125, which may, for example, lead to one or more, e.g., autohydrolysis reactors (not shown). Preferably each conduit 125 is provided with one or more screw conveyors or the like extending in the direction of conduit 125. Preferably, more than one housing outlet is provided. An advantage of having more than one outlet is that two treated feedstock streams may be provided from holding tank

100, each of which may be fed to a different downstream process vessel, e.g. a different steam explosion reactor.

As exemplified, housing 116 comprises two housing outlets 124a, 124b defined in base 118 (see Figure 7). Preferably, each outlet 124a, 124b is positioned such that it is not underneath passage 104 (laterally spaced from passage 104) and preferably more than one outlet is provided. An advantage of positioning outlets 124a, 124b laterally from passage 104 is that feedstock may be withdrawn from all of outlet 112 and, more preferably, evenly from across outlet 112. Further, housing outlets 124a and 124b are preferably positioned on opposite sides of housing 116. Accordingly, housing outlets 124a and 124b may direct cellulosic material to two different, e.g., autohydrolysis reactors, positioned on opposite sides of holding tank 100. As exemplified in Figures 1 and 6, housing 116 may have upper wall 166 that extends over the portion of housing 116 positioned laterally of holding tank 100. Top wall 166 may cover the portion of screw conveyor 126 positioned laterally of holding tank 100. Optionally, a grate 168, or other member that provides a window, may be positioned in top wall 166 above the housing outlet(s). Grate 168 permits a worker to observe the travel of feedstock into conduits 125.

As exemplified, the screw conveyors 126 are mounted above base 118, and each screw conveyor extends transversely to axis 105 across all of outlet 112 (i.e. the length L of each screw conveyor extends at least from a first side of outlet 112 to a second side of outlet 112). Each screw conveyor 126 comprises a shaft 128 and at least one helical flight 130 extending about the shaft, and is configured to rotate to engage material exiting outlet 112, and to convey it towards one of the housing outlets 124a, 124b. Shaft 128 may be rotatably mounted by any means known in the art. As exemplified, shaft 128 has one end journaled in a bearing housing 164 and a second end journaled in a transmission housing 162.

In the embodiment shown, housing 116 comprises four screw conveyors 126, which are arranged in pairs. Each pair comprises two adjacent screw conveyors 126 which convey the cellulosic feedstock in the same direction

towards a common housing outlet 124a or 124b. In the embodiment shown, first pair 132a comprises screw conveyors 126a and 126b, which rotate about respective first 134a and second 134b generally parallel axes, and second pair 132b comprises screw conveyors 126c, and 126d, which rotate about respective first 134c and second 134d generally parallel axes. Each of axes 134 are preferably horizontal, but may be at an angle of up to 45° or greater from the horizontal. Accordingly, screw conveyors 126a and 126b transport treated feedstock to outlet 124a and screw conveyors 126c and 126d transport treated feedstock to outlet 124b, which is on an opposed side to outlet 124a. It will be appreciated that screw conveyors 126a, 126b, 126c and 126d extend under essentially all of outlet 112. Therefore, the screw conveyors 126 preferably withdraw treated feedstock for all portions of outlet 112. Alternately, or in addition, each outlet 124a, 124b may have one or more screw conveyors 126 or other transport member associated therewith.

Referring still to Figure 7, as exemplified, screw conveyors 126a and 126b of first pair 132a may each be rotated in a direction indicated by arrow A1, to feed material from above in a direction indicated by arrow A2 towards housing outlet 124a. Further, screw conveyors 126c and 126d of second pair 132b may each be rotated in a direction indicated by arrow A3, to feed material from above in a direction indicated by arrow A4 towards housing outlet 124b.

In order to permit each screw conveyors 126 to be rotated, in a particular direction of rotation, each screw conveyor may be driven by its own drive motor 160. As shown in Figures 6 and 7, each shaft 128 extends outwardly past sidewall 120 into a transmission housing 162 wherein motor 160 is drivingly connected to shaft 128. Any driving linkage known in the art may be used. It will be appreciated that in an alternate embodiment, two or more shafts may be driven by a single motor 160.

Accordingly, as exemplified, housing outlets 124a and 124b are positioned on laterally opposite sides of housing 116, and each helical flight 130 is right-handed. Accordingly, direction A1 and direction A3 are opposite to each

other, and directions A2 and A4 are opposite to each other. However, in alternate embodiments, housing outlets 124a and 124b may be positioned on the same lateral side as each other. In such an embodiment, directions A1 and A3 may be substantially the same, and directions A2 and A4 may be substantially the same. In yet further alternate embodiments, the helical flight 130 of the first pair 132a of screw conveyors 126a, 126b, may be right handed, and the helical flight 130 of the second pair 132b of screw conveyors 126c, 126d may be left handed. Accordingly, in such an embodiment, directions A1 and A3 may be the same, and direction A2 and A4 may be opposite. It will be appreciated that each pair of screw conveyors 126 may be configured such that they rotate in opposite directions. For example, screw conveyor 126a may be configured to rotate clockwise and screw conveyor 126b may be configured to rotate counterclockwise.

It will be appreciated that in alternate embodiments, one or more screw conveyors 126 may be otherwise configured. For example, housing 116 may comprise only one screw conveyor 126 and one outlet, or housing 116 may comprise a plurality of screw conveyors which are not arranged in pairs (e.g. the screw conveyors may be arranged in sets of three, or as single screw conveyors), or housing 116 may comprise more than two pairs of screw conveyors. For example, in an alternate embodiment shown in Figure 9, holding tank 100 comprises four housing outlets, each being upstream from a conduit 125, and four pairs 132 of screw conveyors 126.

Referring still to Figures 5-7, at least one of the screw conveyors 126, and preferably all of the screw conveyors 126, has a variable pitch along its length. That is, the pitch of helical flight 130 is not constant along the length L of at least one of the screw conveyors 126.

For example, in the embodiments shown, each screw conveyor has a first end 158 proximal to its respective housing outlet (i.e. the outlet 124a or 124b towards which it conveys cellulosic feedstock), and a second end 156 distal to its respective housing outlet 124a or 124b (shown in Figure 7). The pitch of helical flight 130 at first end 158 is greater or wider than the pitch of helical flight

130 at second end 156. For example, the pitch at the first end may be between about 14 inches and about 88 inches, and the pitch at the second end may be between about 4 inches and about 8 inches.

In the embodiments shown, the pitch of each helical flight 130 varies continuously, and preferably at a constant rate, between the first end 158 and the second end 156. That is, the pitch gradually becomes wider towards each discharge member outlet 124a, 124b. In alternate embodiments, an abrupt transition between wider and narrower regions of flight may occur. For example, each screw conveyor may have a first region extending from first end 158 towards a mid-point of screw conveyor 126, and a second region extending from second end 156 towards the midpoint. The first region may have a first range of pitch and the second region has a second range of pitch. For example, the first range of pitch may be between about 14 inches and about 18 inches, and the second range of pitch may be between about 4 inches and about 8 inches. In yet another embodiment, each screw conveyor may comprise an intermediate region between the first region and the second region, and the intermediate region may have a third range of pitch that is less than the first range of pitch and more than the second range of pitch. For example, the third range of pitch may be between about 6 inches and about 10 inches.

Preferably, the screw conveyors 126 of each pair 132 have the same pitch at any location along their lengths. That is, the helical flight of screw conveyors 126a and 126b is essentially identical, and the helical flight of screw conveyors 126c and 126d is essentially identical.

Furthermore, the pitch of a first pair of screw conveyors is preferably a mirror image of the pitch of a second pair of screw conveyors, which convey the cellulosic feedstock in a direction opposite to the first pair of screw conveyors. That is, the pitch of screw conveyors 126a and 126b, which convey cellulosic material in direction A2, is a mirror image of the pitch of screw conveyors 126c and 126d, which convey cellulosic material in a direction A4.

Providing each screw conveyor with a variable pitch, and more specifically with a narrower pitch distal to the housing outlet permits more equal

amounts, and may allow for substantially equal amounts, of cellulosic feedstock to be withdrawn from each portion of outlet 112. That is, material deposited in screw conveyor 126 at the distal end 156 will be conveyed towards the respective outlet 124a, 124b for that screw conveyor. As that material is transported laterally, the pitch of the screw increases permitting additional material to be deposited directly in the screw conveyor from outlet 112. Further increases in the pitch will permit additional portions of the material to fall into screw conveyor. The portion or portions of the screw conveyor closer to its respective outlet (in the direction of transport) has a wider pitch such that it may accommodate material conveyed from the distal region, as well as material deposited directly thereon from passage 104. Accordingly, feedstock is withdrawn from across all of outlet 112.

Referring to Figures 5 and 10, holding tank apparatus 100 preferably further comprises a heating jacket 136 provided on at least a portion of holding tank apparatus 100. Preferably, the at least one sidewall is provided with a heating jacket. For example, in the embodiment shown, heating jacket 136 surrounds all of each sidewall 102a-102d. Heating jacket 136 may comprise a plurality of outer walls 140 that are generally parallel to and spaced from the sidewalls so as to define an enclosure 142 therebetween. A fluid may be passed through enclosure 142 from an inlet (not shown) to an outlet (not shown) so that a heated fluid is passed through enclosure 142. Heating jacket 136 may be of any construction known in the art. Accordingly, the cellulosic material may be heated to a predetermined temperature, or maintained at a predetermined temperature as it passes through holding tank apparatus 100.

Referring to Figure 5, in a further preferred embodiment, housing 116 also comprises a second heating jacket 146 provided by housing 116. In the embodiment shown, heating jacket 146 is configured similarly to heating jacket 136, and may comprise an outer wall 154 spaced outwardly from sidewalls 120 and/or base 118 and is configured for passing a heated fluid through an enclosure 150 defined between outer walls 154 and sidewalls 120 and/or base 118. Heating jacket 146 may be of any construction known in the art.

In some embodiments, one or more temperature sensors may be provided in passage 104. For example, a first thermocouple (not shown) may be provided in the upper portion 106 of passage 104, to measure the temperature of the cellulosic feedstock entering inlet 110, and a second thermocouple (not shown) may be provided in the lower portion 108 of passage 104, to measure the temperature of the cellulosic feedstock exiting outlet 112. In some embodiments, one or more displays (not shown) may be coupled to the one or more temperature sensors, such that a user may view the measured temperatures, and optionally, adjust the amount of heat provided to holding tank 100 based on the measured temperatures. In further embodiments, the one or more sensors may be coupled to a processor, which may automatically adjust the amount of heat provided to holding tank 100 based on the measured temperatures.

A method of treating a cellulosic feedstock that may be used for ethanol production will now be described. Although the method will be described with reference to holding tank apparatus 100, it will be appreciated that the method may be carried out using an alternate apparatus, and holding tank 100 may be operated according to an alternate method.

A suitable cellulosic feedstock is preferably first subjected to moisture impregnation to raise the moisture content of the feedstock to a predetermined level prior to entry to the holding tank. Preferably, the moisture content of the feedstock upon entry to the holding tank is from about 30 wt % to about 60 wt%, preferably from about 45 wt% to about 55 wt %. The cellulosic feedstock may be obtained from, for example, a pre-treatment device such as

impregnator 10, in which moisture is added to the cellulosic feedstock to raise the moisture content from, e.g., less than about 15% to between about 30% and about 60 wt% upon entry to the holding tank. Preferably, the moisture content is between about 45wt% and about 55wt% upon entry to the holding tank.

The cellulosic feedstock is passed from the outlet of the impregnation chamber to the inlet of a holding tank. For example the cellulosic feedstock may be passed from outlet 18 of impregnation chamber 10, into inlet 110 of holding tank 100.

The cellulosic feedstock, with or without being subjected to impregnation, is then preferably passed downwardly through the holding tank. For example, referring to holding tank 100, inlet 110 is disposed at an elevation above outlet 112. Accordingly, the material may migrate downwardly from the inlet towards the outlet under the force of gravity. Furthermore, in embodiments wherein lower portion 108 has a greater cross sectional area than upper portion 106, the material will further migrate laterally as it migrates downwardly.

Preferably a generally constant residence time is maintained in the holding tank. That is, the holding tank is preferably operated continuously at steady state conditions, such that all parts of each portion or layer of feedstock added at inlet 110 pass downwardly to outlet 112 at about the same rate. This result may be achieved by withdrawing feedstock from all portions of the outlet 112. For example, the material may be removed from the outlet by operating one or more screw conveyors, such as screw conveyors 126 described hereinabove, such that feedstock from all parts of the outlet 112 (e.g., all of the same horizontal layer of feedstock in the outlet 112) are collected concurrently in the screw conveyor and transported to an outlet or downstream passage. It will be appreciated that the amount of material that is withdrawn from each part of the holding tank outlet may be varied by adjusting the pitch of the flight of the screw conveyor. By enlarging the pitch at certain locations, the amount of feedstock withdrawn at those locations may be increased.

It will be appreciated that, in use, there may be an initial start up phase, wherein material is not removed from the holding tank, and the tank is filled with cellulosic feedstock from impregnation chamber 12.

The residence time may be, for example, between about 10 and about 30 minutes. An advantage of this method is that a generally uniform residence time of the feedstock in the vessel may be achieved. For example, the variance of the residence time may be up to 5 minutes, preferably, less than 3 minutes and more preferably less than 2 minutes.

In one embodiment, the method comprises laterally conveying the cellulosic feedstock from the passage of the holding tank. Accordingly, once the feedstock reaches the exit (outlet) of the holding tank, the feedstock is conveyed laterally to, e.g., one or more conduits in flow communication with a downstream process unit. For example, the holding tank may comprise a discharge member, such as discharge member 116, adjacent lower end 108. One or more screw conveyors 126 of the discharge member may convey the cellulosic feedstock laterally across outlet 112, as described hereinabove.

Alternately, or in addition, in other embodiments, the cellulosic material is actively withdrawn from essentially the entirety of outlet 112. The feedstock is therefore moved at least with the assistance of machinery out of the holding tank. For example, discharge member 116 may comprise a plurality of screw conveyors extending across outlet 112, which, when rotated, engage the cellulosic material adjacent the entirety of the outlet 112, and convey it towards a discharge member outlet, as described hereinabove.

Alternately, or in addition, in other embodiments, generally equally amounts of the cellulosic material are preferably withdrawn from each portion of the outlet 112. In such an embodiment, a screw conveyor having different pitches (progressively wider pitches) may be used to convey the cellulosic feedstock laterally across the outlet of the holding tank. For example, a screw conveyor 126 may have a helical flighting having a first pitch adjacent a discharge member outlet, and second pitch narrower than the first pitch distal to

the discharge member outlet. Accordingly a generally equal amount of feedstock may be withdrawn from the region adjacent a discharge member outlet, and from a region distal to a discharge member outlet.

In some embodiments, a first portion of the cellulosic feedstock is preferably withdrawn in a first lateral direction and a second portion of the cellulosic feedstock withdrawing a second portion of the cellulosic feedstock is preferably in a second lateral direction, which is preferably opposite to the first direction. For example, the holding tank may comprise a first pair of screw conveyors and a second pair of screw conveyors. Each screw conveyor may comprise a right-handed helical flighting, and the first pair of screw conveyors may be rotated in a first direction to convey the cellulosic feedstock in a first lateral direction, and the second pair of screw conveyors may be rotated in a second direction to convey the cellulosic feedstock in a second lateral direction.

In some embodiments, the method further comprises maintaining a temperature in the holding tank between about 50°C and about 75°C. For example, the holding tank may be optionally provided with a heating jacket, such as heating jacket 136 and/or discharge member 116 may be optionally provided with a heating jacket 146. The heating jacket may serve to heat the walls of the holding tank and/or the discharge member, such that the material within the holding tank is maintained at or raised to a temperature between 50°C and about 75°C.

It will be appreciated that certain features of the invention, which are, for clarity, described in the context of separate embodiments or separate aspects, may also be provided in combination in a single embodiment. Conversely, various features of the invention, which are, for brevity, described in the context of a single embodiment or aspect, may also be provided separately or in any suitable sub-combination.

Although the invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, it is

intended to embrace all such alternatives, modifications and variations that fall within the spirit and broad scope of the appended claims. In addition, citation or identification of any reference in this application shall not be construed as an admission that such reference is available as prior art to the present invention.

We claim:

1. A holding tank apparatus for preparing a cellulosic feedstock, comprising:
 - (a) at least one sidewall defining a volume having an upper portion and a lower portion;
 - (b) at least one inlet adjacent the upper portion;
 - (c) at least a one outlet adjacent the lower portion, at an elevation below the inlet; and,
 - (d) a plurality of screw conveyors comprising a first pair of screw conveyors and a second pair of screw conveyors for conveying the cellulosic feedstock laterally across the outlet, the first and second pairs of screw conveyors having a variable pitch along their respective lengths, wherein the first pair of screw conveyors convey cellulosic feedstock in a first direction and the second pair of screw conveyors conveys cellulosic feedstock in an opposite direction.
2. The apparatus of claim 1, wherein the first and second pairs of screw conveyors each have a first end and a second end, and the pitch at the first end of each pair of conveyors differs from the pitch at the respective second end.
3. The apparatus of claim 2, wherein the first and second pairs of screw conveyors each comprise a first region having a first range of pitch, and a second region having a second range of pitch.
4. The apparatus of claim 3, the first and second pairs of screw conveyors each further comprising an intermediate region between their respective first and second regions, the intermediate region having a third range of pitch between the first range of pitch and the second range of pitch.

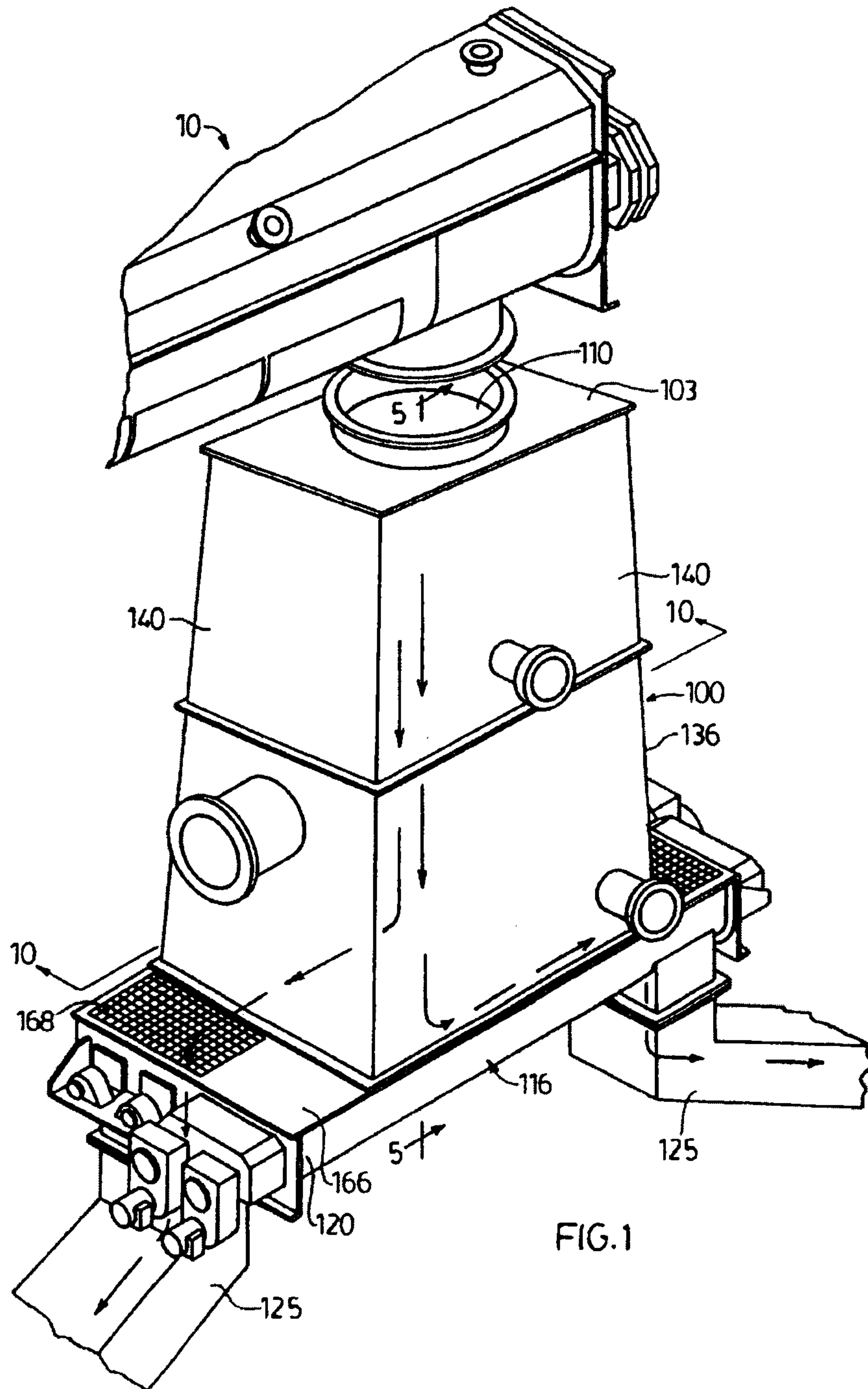
5. The apparatus of claim 1, wherein the first and second pairs of screw conveyors each have a first end and a second end, and the pitch decreases from each first end to the respective second end.
6. The apparatus of claim 5, wherein the pitch of the first and second pairs of screw conveyors varies at a constant rate between each first end and the respective second end.
7. The apparatus of claim 5, wherein the outlet defines a plurality of portions and the pitch of each of the first and second pairs of screw conveyors varies such that approximate equal portions of feedstock are withdrawn from each portion of the outlet.
8. The apparatus of claim 1, wherein the pitch of the first pair of screw conveyors at any location along their length is essentially the same and the pitch of the second pair of screw conveyors at any location along their length is essentially the same.
9. The apparatus of claim 1, wherein the pitch of the first pair of screw conveyors is a mirror image of the pitch of the second pair of screw conveyors.
10. A holding tank apparatus for preparing a cellulosic feedstock, comprising:
 - (a) at least one sidewall defining a volume having an upper portion and a lower portion;
 - (b) at least one inlet adjacent the upper portion;
 - (c) at least a one outlet adjacent the lower portion, at an elevation below the inlet; and,
 - (d) a plurality of screw conveyors comprising a first pair of screw conveyors and a second pair of screw conveyors for conveying the cellulosic feedstock laterally across the outlet, the first and second pairs of

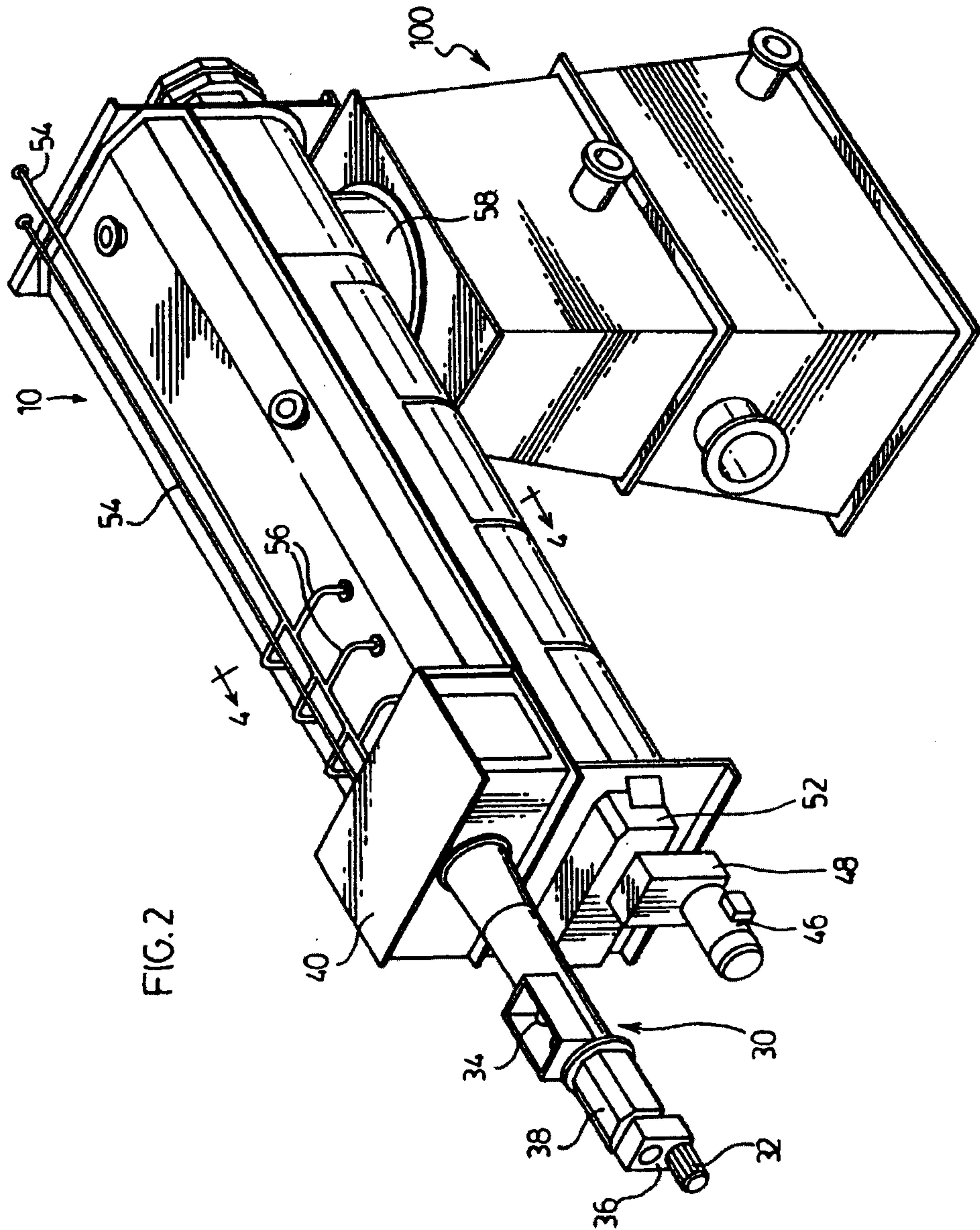
screw conveyors having a variable pitch, the first pair of screw conveyors conveys cellulosic feedstock in a first direction and the second pair of screw conveyors conveys cellulosic feedstock in a second direction, wherein the first direction and the second direction are substantially opposite, and wherein the first pair of screw conveyors is rotatable in a first direction of rotation, and the second pair of screw conveyors is rotatable in a direction of rotation opposite the first direction of rotation.

11. The apparatus of claim 1, wherein the plurality of screw conveyors extends across all of the outlet.
12. The apparatus of claim 1, further comprising a heating jacket provided on at least a portion of the apparatus.
13. The apparatus of claim 1, wherein the lower portion has a greater cross sectional area than the upper portion.
14. The apparatus of claim 1, wherein the at least one sidewall comprises a first sidewall and a second sidewall opposed to the first sidewall, the first and second sidewalls diverging relative to each other from the upper portion to the lower portion.
15. The apparatus of claim 14, wherein the at least one sidewall comprises a third sidewall and a fourth sidewall opposed to the third sidewall, the third and fourth sidewalls extending between the first and second sidewalls, the third and fourth sidewalls diverging relative to each other from the upper portion to the lower portion.
16. The apparatus of claim 10, wherein the first and second pairs of screw conveyors each have a first end and a second end, and the pitch at the first end of each pair of conveyors differs from the pitch at the respective second end.

17. The apparatus of claim 16, wherein the first and second pairs of screw conveyors each comprise a first region having a first range of pitch, and a second region having a second range of pitch.
18. The apparatus of claim 17, the first and second pairs of screw conveyors each further comprising an intermediate region between their respective first and second regions, the intermediate region having a third range of pitch between the first range of pitch and the second range of pitch.
19. The apparatus of claim 10, wherein the first and second pairs of screw conveyors each have a first end and a second end, and the pitch decreases from each first end to the respective second end.
20. The apparatus of claim 19, wherein the pitch of the first and second pairs of screw conveyors varies at a constant rate between each first end and the respective second end.
21. The apparatus of claim 20, wherein the outlet defines a plurality of portions and the pitch of each of the first and second pairs of screw conveyors varies such that approximate equal portions of feedstock are withdrawn from each portion of the outlet.
22. The apparatus of claim 10, wherein the pitch of the first pair of screw conveyors at any location along their length is essentially the same and the pitch of the second pair of screw conveyors at any location along their length is essentially the same.
23. The apparatus of claim 10, wherein the pitch of the first pair of screw conveyors is a mirror image of the pitch of the second pair of screw conveyors.
24. The apparatus of claim 10, wherein the plurality of screw conveyors extends across all of the outlet.

25. The apparatus of claim 10, further comprising a heating jacket provided on at least a portion of the apparatus.
26. The apparatus of claim 10, wherein the lower portion has a greater cross sectional area than the upper portion.
27. The apparatus of claim 10, wherein the at least one sidewall comprises a first sidewall and a second sidewall opposed to the first sidewall, the first and second sidewalls diverging relative to each other from the upper portion to the lower portion.
28. The apparatus of claim 27, wherein the at least one sidewall comprises a third sidewall and a fourth sidewall opposed to the third sidewall, the third and fourth sidewalls extending between the first and second sidewalls, the third and fourth sidewalls diverging relative to each other from the upper portion to the lower portion.





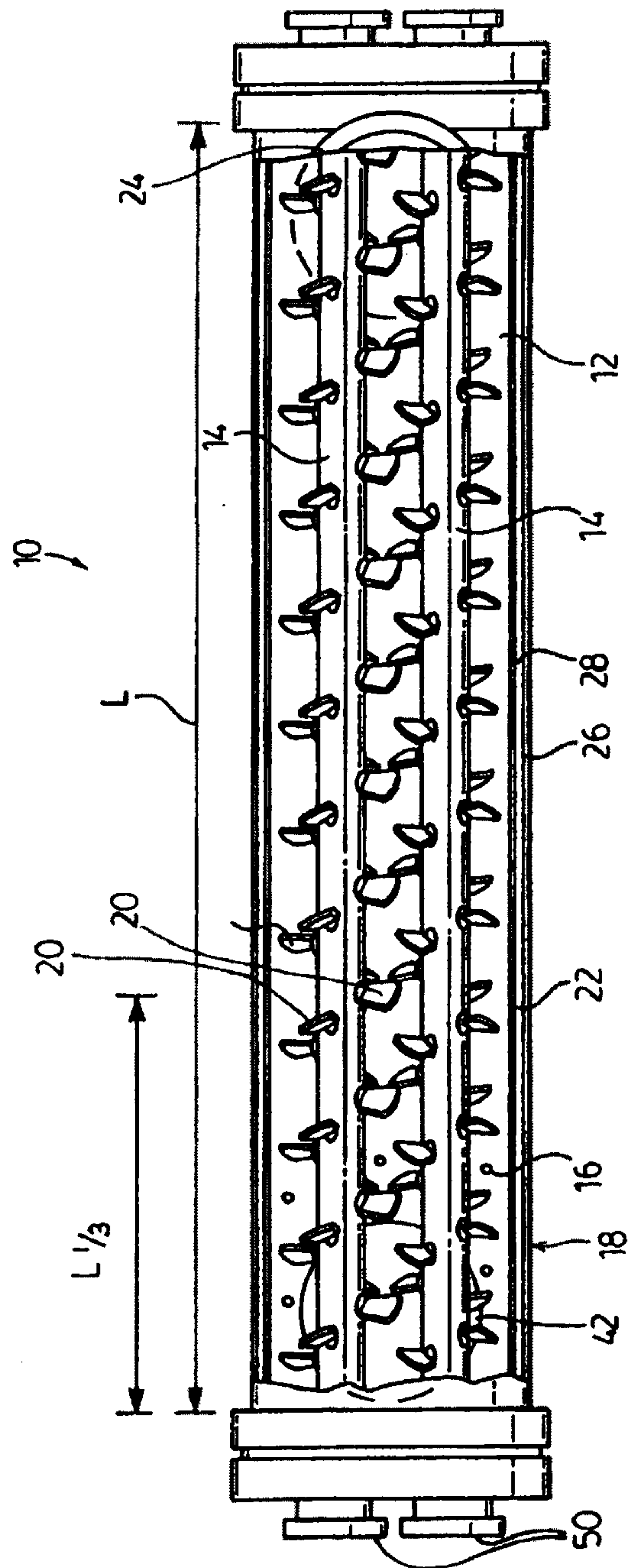


FIG. 3

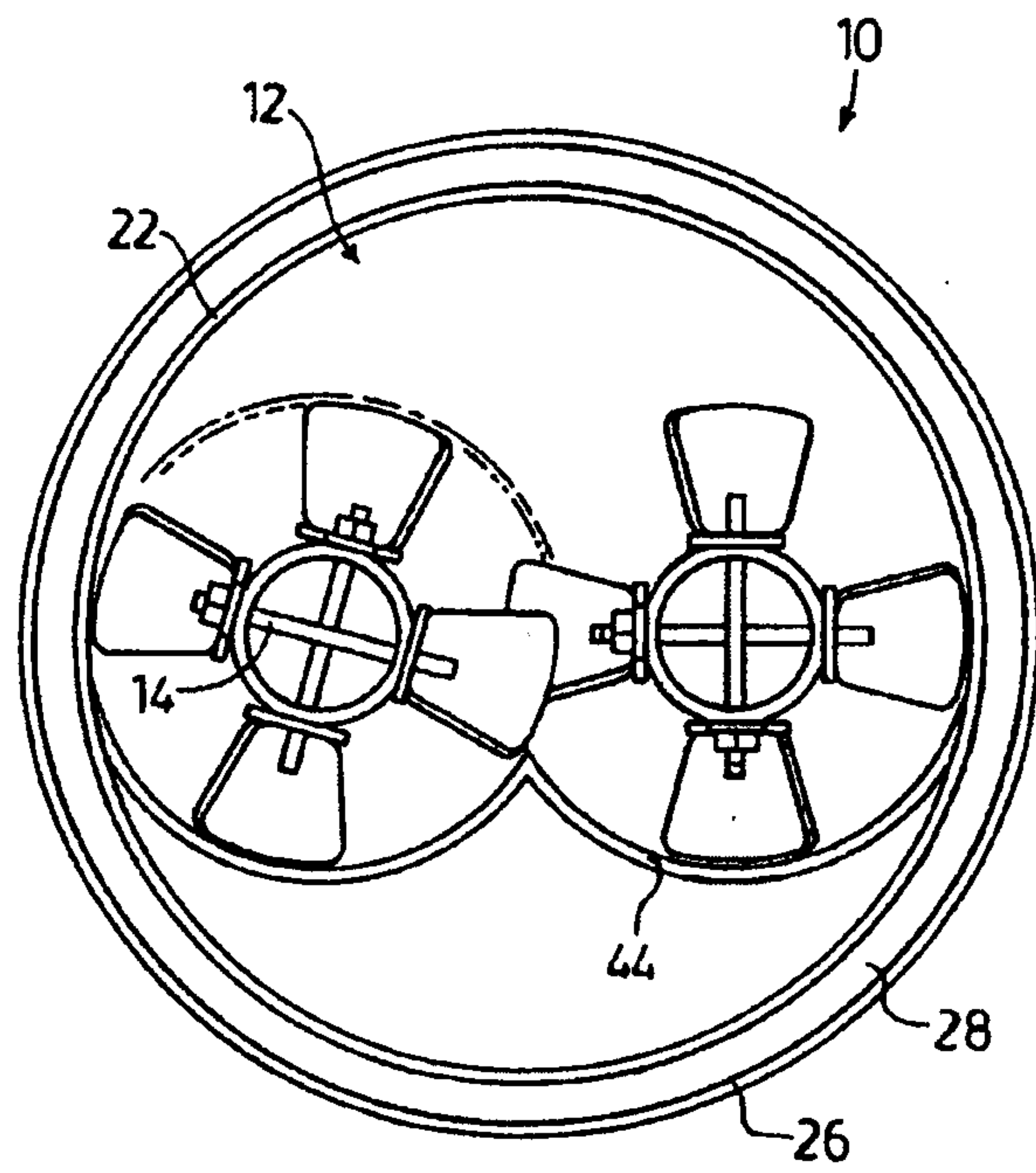
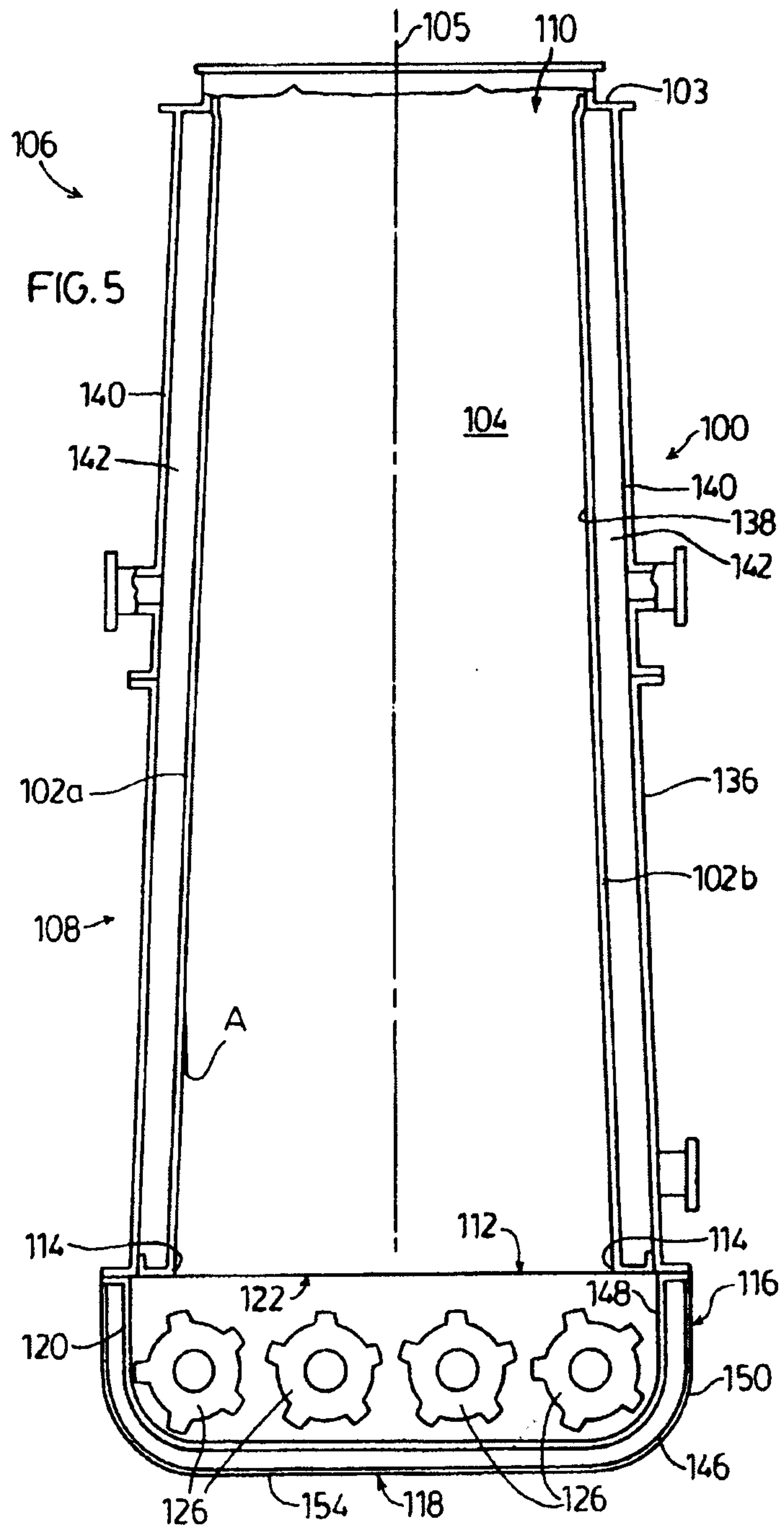
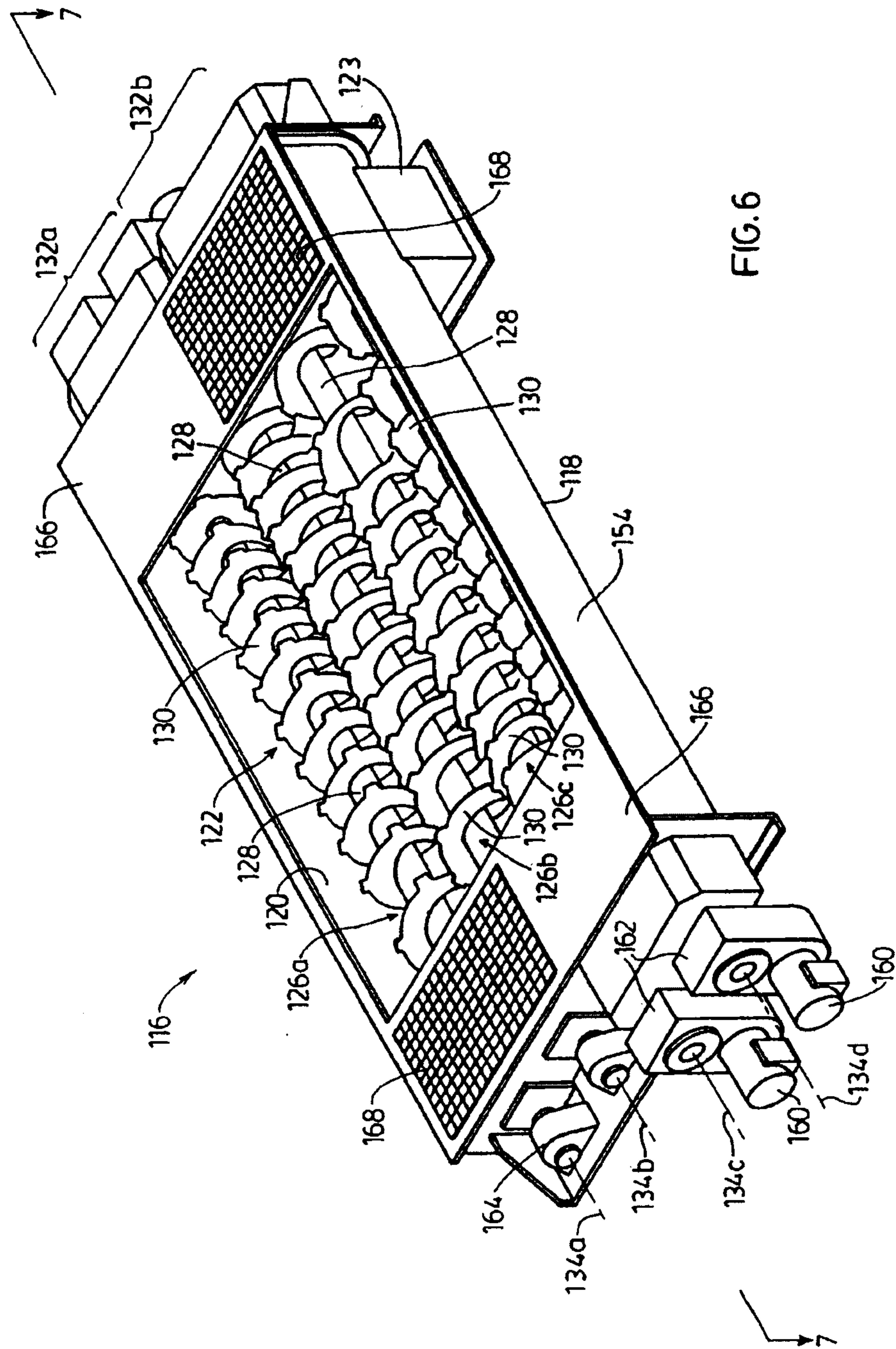


FIG. 4





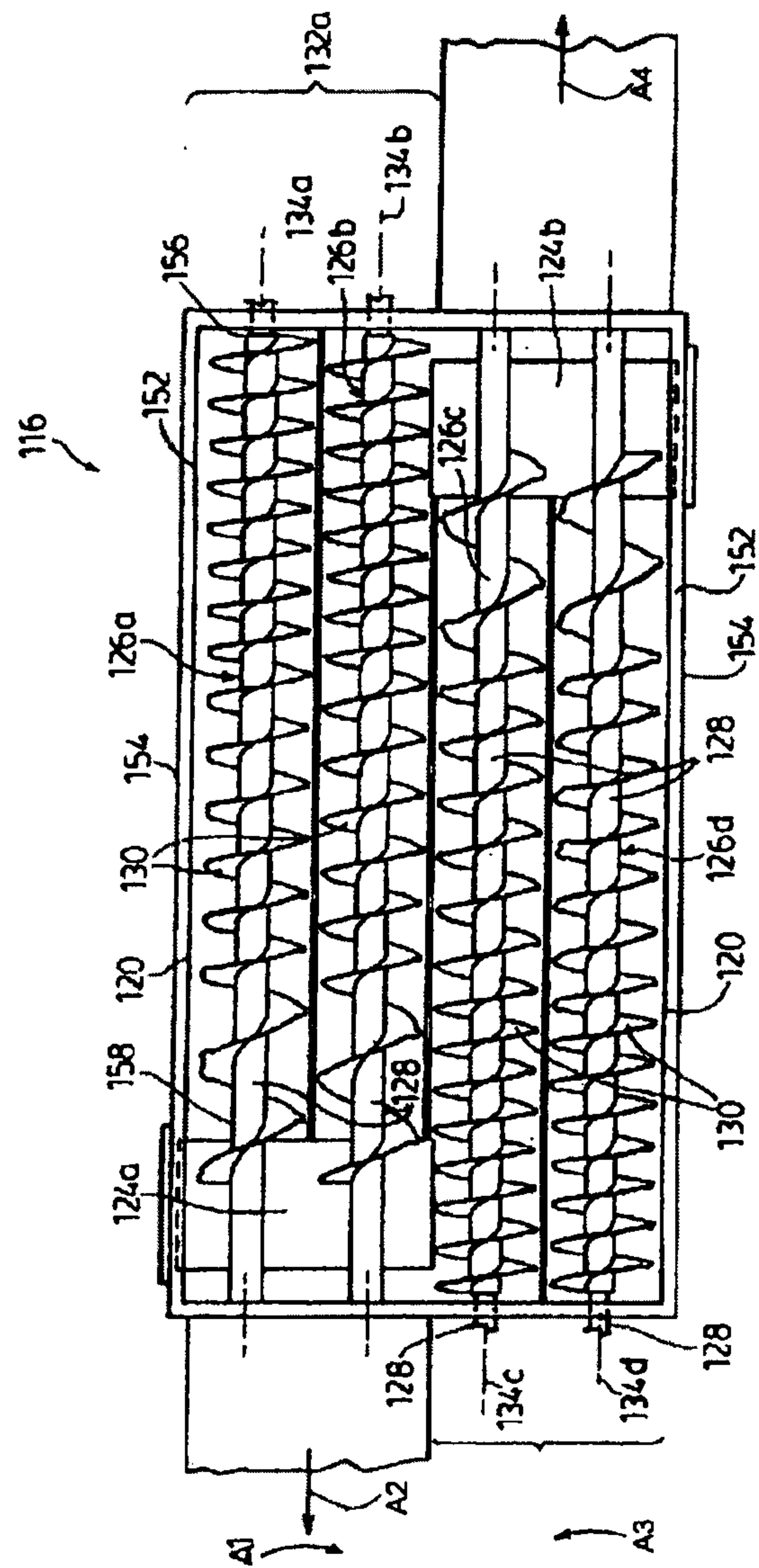


FIG. 7

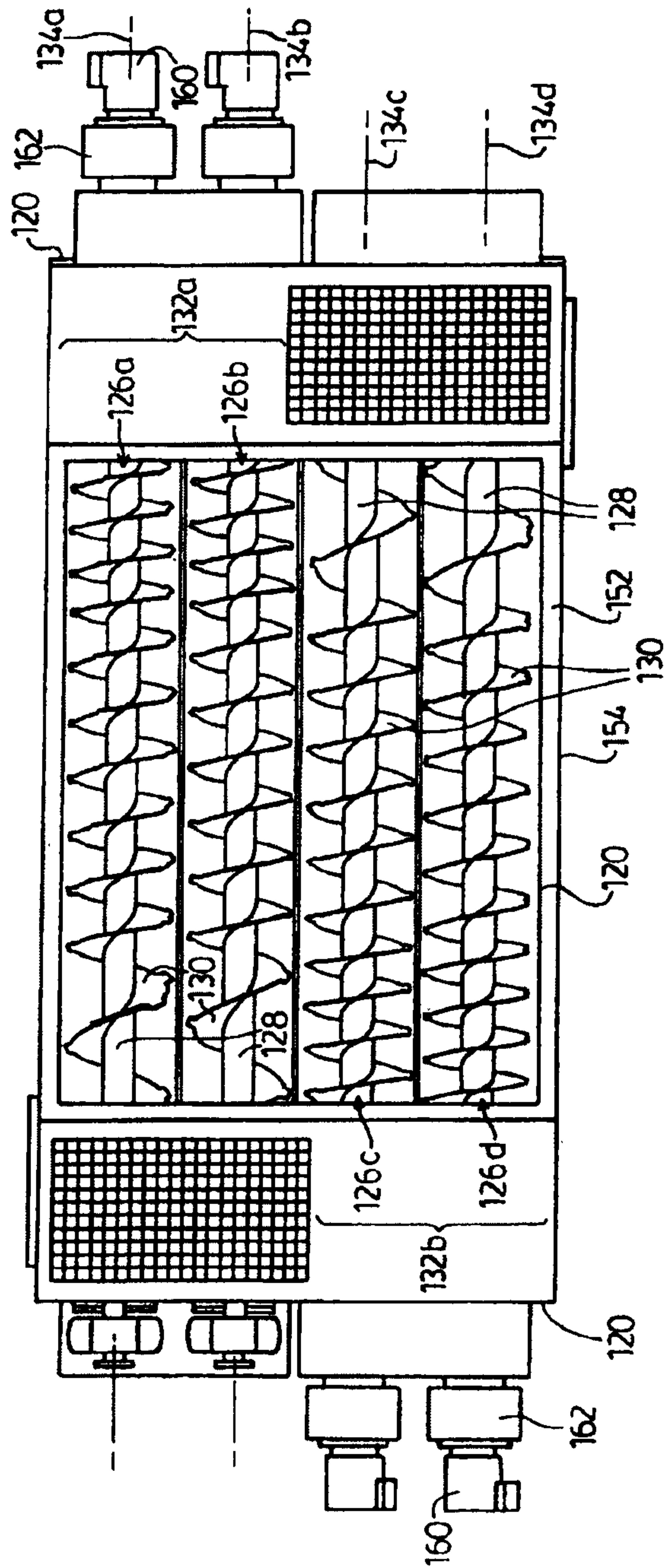
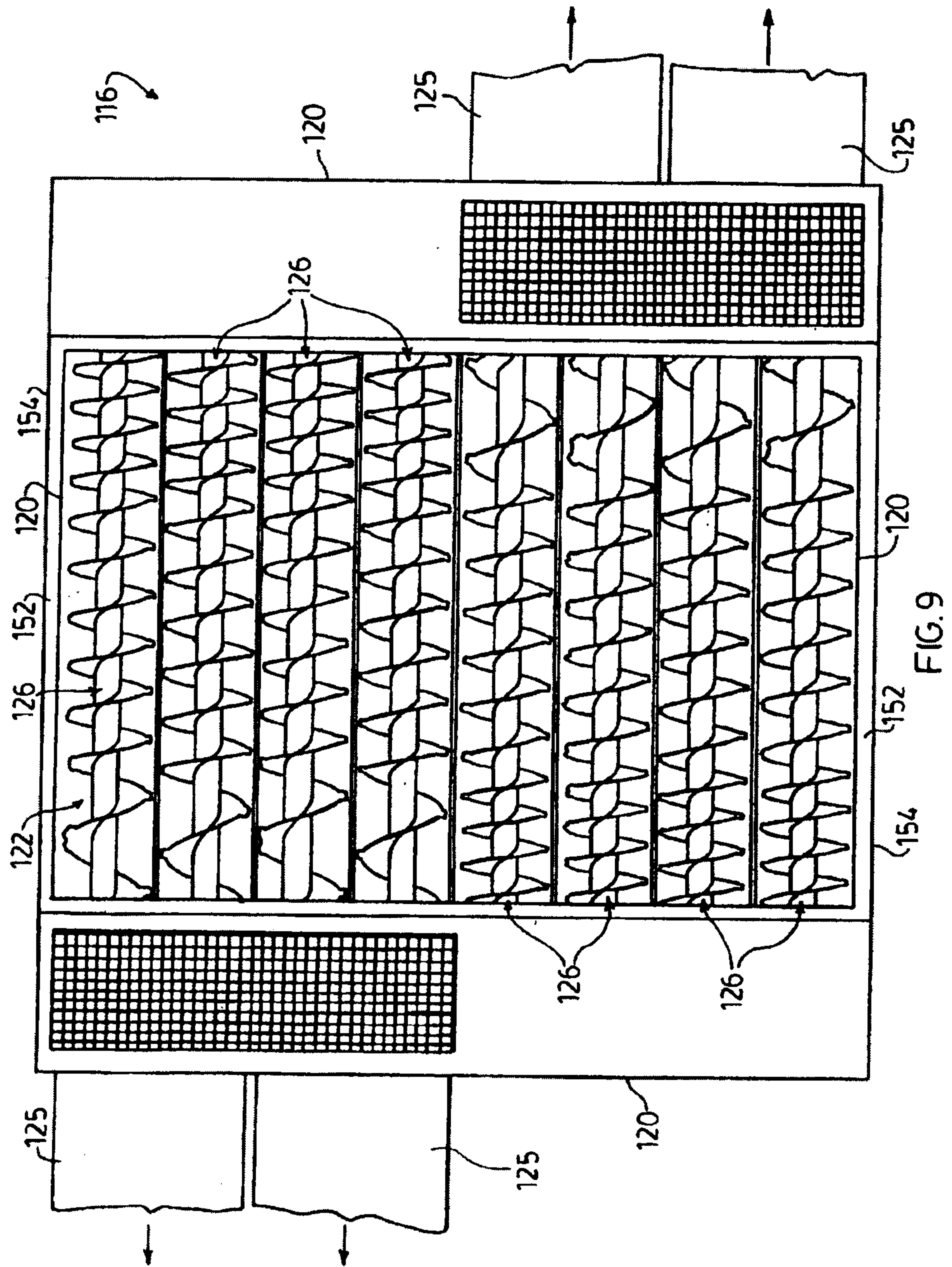


FIG. 8



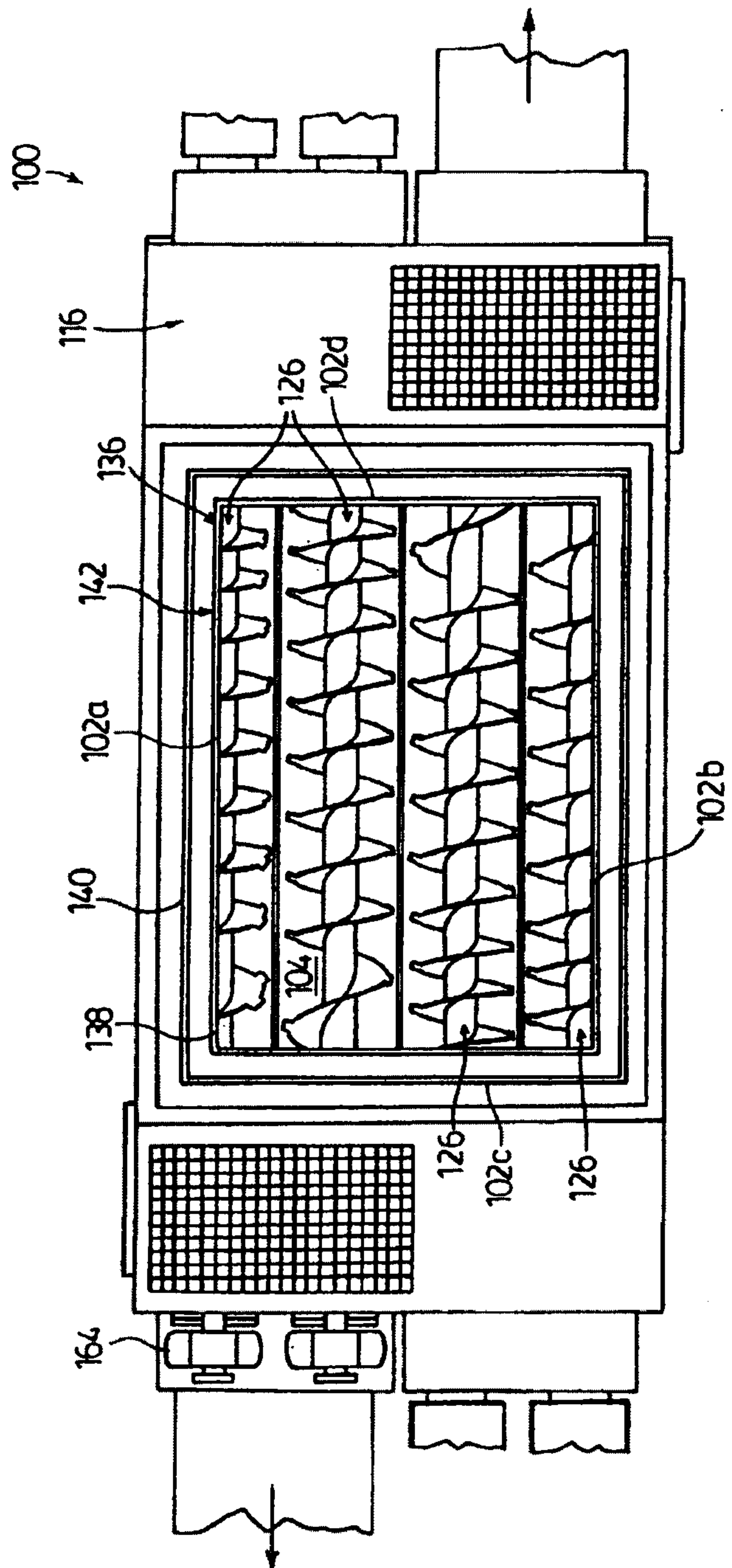


FIG.10

